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Spatial data and modelling for the prioritisation of conservation areas in the Alpine region of the Canton of Vaud

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SPATIAL DATA AND MODELLING FOR THE PRIORITISATION OF CONSERVATION AREAS IN THE ALPINE REGION OF THE CANTON OF VAUD

ANA RUTE PIRES CARDOSO

ABSTRACT

Increasing awareness of the impact of biodiversity loss and natural system instability on human life is changing the societal perception of the environment and the amount of effort put into solving environmental problems.

In spatial planning, this translates into a quest for the sustainable use of the territory, allocating areas to their most suitable usage while managing conflicting interests and forces. Conservation areas are the cornerstone of any spatial strategy for nature conservation, but are strongly affected by socio-economic constraints that affect their implementation and maintenance. Prioritising interventions thus becomes fundamental to achieve efficient and effective results.

Conservation planning has come a long way since its infancy, gradually putting aside traditional *ad hoc* reserve selection in favour of a more scientific and systematic approach. This development has been supported by advances in technology, especially in the area of geographic information systems, which allow for improved acquisition and faster treatment of spatial data. Modelling has also became a fundamental scientific activity for conservation planning, offering a better understanding of natural and biological phenomena and generating indispensable data used in emerging conservation planning support software.

This dissertation looks at methods for the selection of high-quality areas for conservation, focusing on the maximum cover problem and analysing how traditional strategies translate into spatial differences on the resulting selection.

The study area chosen to test our methodology is the Alpine region of the Canton of Vaud, in Switzerland, an area known for its biodiversity and cultural richness. After a thorough analysis of the area, focused on the biodiversity, socio-economic, political, and legal aspects that affect conservation planning, we decided to concentrate on prioritisation for vegetation conservation.

Using Zonation v4 — a software package developed to aid conservation planning decision — and taking into account the previous analysis, we assess the spatial differences that result from different decisions, such as privileging rarity or richness, weighting species according to different criteria, or including socio-economic costs. We also examine the logic behind existing protected areas and investigate a possible expansion to benefit vegetation conservation.

The outputs and subsequent analysis show the strong influence of both strategic preferences and socio-economic constraints on the priority ranking for potential protected areas. However, regardless of the strategy chosen, some areas are consistently ranked high and are therefore good candidates for further expansion. Furthermore, existing protected areas already show good coverage, and an increase of merely 2% in protected area would suffice to retain almost full representation of the vegetation species under consideration

In the end, there are no perfect or universal solution for conservation planning prioritisation: different spatial translations can yield similar results for biodiversity. The process is an exercise in trade-offs in which software like Zonation can be of great assistance, allowing for an easier assessment of different scenarios and conservation strategies.

KEYWORDS: prioritisation, conservation planning, GIS, Zonation, Vaud

DADOS ESPACIAIS E MODELAÇÃO PARA A PRIORIZAÇÃO DE ÁREAS DE CONSERVAÇÃO NA REGIÃO ALPINA DO CANTÃO DE VAUD

ANA RUTE PIRES CARDOSO

RESUMO

A crescente consciencialização das repercussões da perda de biodiversidade e da disrupção dos sistemas naturais na vida humana tem modificado a percepção dos problemas ambientais e fomentado a mobilização de recursos para os resolver.

Em ordenamento do território, esta preocupação traduz-se na procura de uma ocupação sustentável do espaço, tentando gerir forças e interesses muitas vezes opostos e dificilmente conciliáveis. As áreas protegidas são os alicerces de qualquer estratégia para a conservação ao nível territorial, mas a sua implementação e manutenção é fortemente influenciada por limitações contextuais de origem socioeconómica. Priorizar intervenções e investimentos em conservação de forma a torná-la mais eficaz e eficiente torna-se, assim, essencial.

A planificação para a conservação ambiental e o método de selecção de reservas por esta empregado têm sido alvo de desenvolvimentos nas últimas décadas, passando de uma abordagem pouco científica a um processo sistemático. Esta mudança de paradigma só foi possível devido ao desenvolvimento paralelo de tecnologias de informação geográfica que vieram possibilitar uma melhor e mais rápida aquisição de dados espaciais e seu tratamento.

A modelação tornou-se uma ferramenta científica indispensável no processo de planeamento, permitindo a recolha de informação sobre fenómenos naturais e de dados indispensáveis para a utilização de *software* de ajuda à decisão.

Esta dissertação pretende estudar os métodos empregues na identificação e selecção de áreas a proteger, focando-se no problema da máxima representatividade e na análise de estratégias comuns de priorização na tradução espacial dessa selecção.

A área de estudo escolhida para esta análise foi a zona alpina do Cantão de Vaud, na Suíça, uma área conhecida pela sua biodiversidade e riqueza cultural. Depois de uma análise detalhada às características de biodiversidade, socioeconómicas e político-legais locais, decidimos concentrar o nosso estudo na preservação da vegetação.

Recorrendo ao programa de apoio à decisão em planeamento de conservação Zonation v4, analisámos as diferenças espaciais resultantes de diferentes opções de conservação e dados de entrada, tais como a preferência pela salvaguarda da raridade ou da riqueza biológica, a atribuição de diferentes pesos às espécies com base em critérios vários ou a inclusão de informação socioeconómica. Tentámos ainda apurar a lógica subjacente à criação das reservas existentes e identificar possibilidades de expansão que beneficiariam a conservação.

Concluímos que a tendência para proteger a raridade ou a riqueza tem tradução espacial relevante, sendo, no entanto, as limitações socioeconómicas o maior factor de constrangimento para a salvaguarda de biodiversidade. Independentemente da estratégia usada, certas áreas são consistentemente seleccionadas, mostrando-se boas candidatas para expansão futura. Os resultados revelam ainda que as reservas actuais têm boa cobertura e um aumento de 2% da área seria suficiente para atingir uma representação quase total das espécies consideradas. É possível encontrar soluções interessantes sem comprometer de forma marcante a salvaguarda da biodiversidade.

Em planeamento de conservação, não existem soluções perfeitas e universais, tratando-se antes de um constante exercício de concessões. Programas de ajuda à decisão em planeamento de conservação, como o Zonation v4, demonstram grande potencial, permitindo uma melhor compreensão das alternativas e a sua rápida visualização espacial.

PALAVRAS-CHAVE: priorização, planeamento de conservação, SIG, Zonation, Vaud

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List of Acronyms

ABF	additive benefit function
ANN	artificial neural network
BQP	boundary quality penalty
CAZ	core-area Zonation
CR	critically endangered
DD	data deficient
DET	occupancy-determination
EN	endangered
ENFA	ecological niche factor analysis
ENM	ecological niche model
EU	European Union
GAM	generalised additive model
GBM	generalised boosted model
GIS	geographical information systems
GLM	generalised linear model
IUCN	International Union for Conservation of Nature
LC	least concern
MPA	marine protected area
NE	not evaluated
NGO	non-governmental organisation
NT	near threatened
PA	presence-absence
PB	presence-background
PO	presence-only
RE	regionally extinct
SBS	Swiss Biodiversity Strategy

SCP	systematic conservation planning
SDM	species distribution model
SSI	species of special interest
VU	vulnerable

1 Introduction

1.1 Theme

The drastic loss of biodiversity is a worldwide recognised problem, not only resulting in the loss of important ecological values but also negatively affecting economic and social development.

Biodiversity is essential for human survival. It is estimated that 40% of the global economy and 80% of the sustenance of poor people is directly dependent on biological resources (Organisation for Economic Co-operation and Development, 2004), be it in the form of food, fuel, and medicine supplies, or of the environmental services they provide, which are frequently overlooked.

Meanwhile, the Global Living Planet Index has shown a decline of 52% in vertebrate population over the last 40 years, during the period between 1970 and 2010 (McLellan, 2014). Experts are suggesting that at the actual extinction rates — between 1000 to 10 000 times higher than natural (IUCN, 2007) — one-fourth of plants and vertebrate animals may be heading towards extinction by mid-century (Malcolm, Liu, Neilson, Hansen, & Hannah, 2006).

Not surprisingly, the causes of this quick biodiversity decline are known to be closely related to human activity and its appropriation of territorial space and resources. Habitat destruction and degradation, over-exploitation of resources, pollution, diseases, alien species, and climate change are the main threats faced by biodiversity (IUCN, 2007).

The development of a widespread environmental conscience during the 20th century, generated by the growing awareness of the importance of biodiversity and the increasing impact of the disruption of natural systems on human life, has brought conservation planning to the order of the day (Ministério do Ambiente e do Ordenamento do Território, 2001).

Focusing on land and resource preservation, biodiversity maintenance, and environmental services safeguarding, conservation planning is constantly in search of a sustainable equilibrium between the use of the land and the preservation of values deemed irreplaceable for the future generation.

In a time of strategic spatial planning, based on principles of collaborative decision and the pursuit of territorial resilience, the need to understand the functioning of the territory and the complex systems that integrate it becomes fundamental.

Spatial information and spatial modelling, greatly boosted by the developments seen in geographical information systems (GIS) in the last few decades, became essential tools for informed, scientifically validated, technically supported spatial decisions.

That validation is particularly important in the environmental conservation domain, which more often than not faces opposition from economic entities and local populations that see the creation of protected areas and reserves as restrictive and detrimental for their way of life (Margules & Pressey, 2000).

This dissertation looks at methods for selecting high-quality areas for conservation. We focus our study in the Alpine region of the Canton of Vaud, a region marked by a long human occupation and a recognised richness of natural values. These natural values are under strong pressure and measures are needed to preserve them for future generations.

Nonetheless, like in most places around the world, it is not always possible to completely reconcile human interests and the protection of every species and habitat; establishing conservation goals and identifying priority areas for conservation becomes an unavoidable task.

1.2 Goals and objectives

Over the last few decades, the scientific work done in conservation planning has been steadily increasing, propelled by the growing recognition of its importance and by advances in diverse areas of knowledge.

This work has been mainly led by biologists and biogeographers and, even though they achieved interesting and scientifically validated results, we continue to see a gap between their research and real-world conservation planning. The field of spatial planning has given surprisingly few contributions to the subject (A. T. Knight et al., 2008) (Kukkala & Moilanen, 2013).

The state of affairs seems to imply a particularly deficient communication between the scientific community and the spatial planning technicians responsible for the actual planning.

It is clear that there is a need to bring both areas together under the common interest that they share in sustainable territorial planning, as well as a need to promote opportunities to share data and experience and to improve communication in order to achieve better results in ecological preservation.

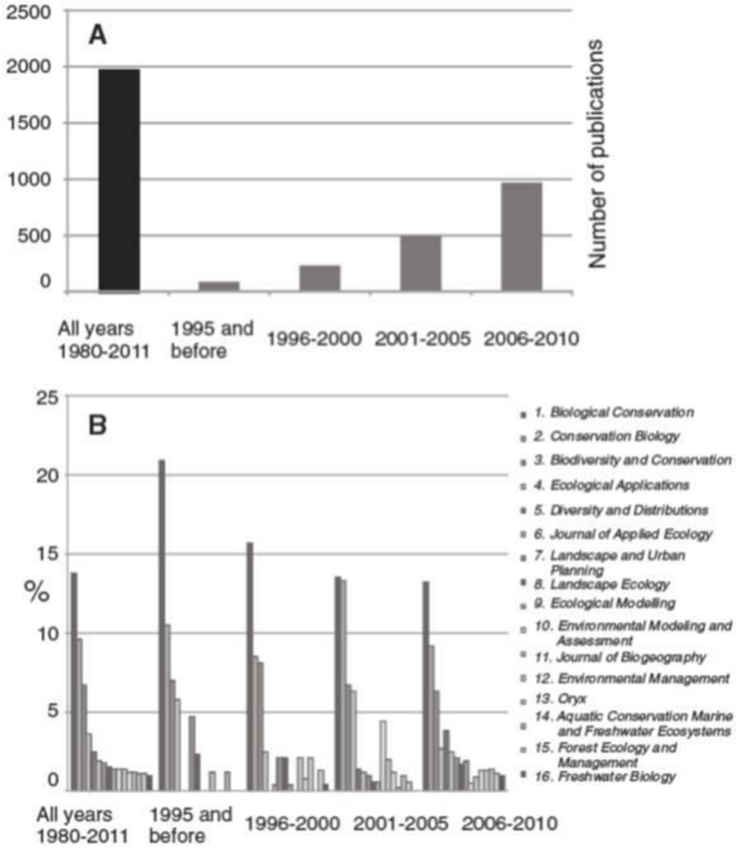

Figure 1: Evolution of the number of scientific publications in systematic conservation planning (SCP) and distribution by the sixteen journals in which they most often appear (Kukkala & Moilanen, 2013)

This dissertation, carried out in the framework of the Masters in Spatial Planning and Geographical Information Systems at Universidade NOVA de Lisboa and developed in the Spatial Ecology Group at the University of Lausanne, aims to contribute to a better integration of species distribution data with traditional spatial planning concerns such as legislation, culture, and economics in the scope of prioritisation in conservation planning.

The area of study chosen for this work is the Alpine region of the Canton of Vaud, which is the target of a new transdisciplinary research platform project (RechAlp[1]) that aggregates diverse information, mainly in the natural sciences. We make use of existing high quality data

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[1] http://rechalpvd.unil.ch/

regarding species distribution gathered and created by the Spatial Ecology Group, with a main focus on vegetation, as well as other socio-economic data relevant for effective conservation planning.

Using Zonation v4 to solve the maximum cover problem, we developed a methodology that aims to:

- identify priority areas for conservation taking into account different objectives and goals
- evaluate in which way the different objectives and goals affect the use of data and the results of the prioritisation
- analyse the current protected areas in the face of different prioritisation strategies
- identify pros and cons of the current systematic conservation planning approach and the use of decision support software

1.3 Structure

This dissertation is organised in seven chapters. Chapter 1 introduces the main ideas and goals underlying our work. Chapters 2 and 3 present a literature review of the topics addressed, the former focusing on the relation between conservation planning and spatial planning and the latter on their relation to GIS technologies and spatial data, allowing for a better understanding of the general context. Chapter 4 covers the methodology employed throughout the work, describing the most important steps and approaches used for framing and analysing our study area and outlining new and more detailed goals and procedures. Chapter 5 frames and analyses the context surrounding the study area, focusing on policy and legislation, socio-economics, and biodiversity. Chapter 6 presents and discusses the results of the computation for different conservation planning prioritisation strategies. Finally, Chapter 7 draws some conclusions and proposes possible avenues for future work.

2 Spatial Planning and Conservation Planning

2.1 Defining spatial planning and conservation planning

Planning and prioritising are two terms that often come together. The first, planning, is the act of making plans, of thinking about a task, determining goals, and defining the means to achieve them; it is intrinsically linked to predicting and preparing for multiple scenarios with which we might be confronted in the future. The second, prioritising, is the act of arranging and establishing an order of importance, of attributing weights of significance for doing the right task at the right moment, and of ensuring that a plan makes the best use of normally limited resources.

Both concepts have been appropriated by many fields of study, particularly those that deal with high complex issues and widespread conflicts of interest. One such field is the management and organisation of territorial space and of the human activities that take place within, commonly referred to as spatial planning.

Although interest in spatial planning is not new, the name by which it is best known nowadays is relatively recent. According to (Williams, 1996), spatial planning is a term developed in the course of shaping a European position in the field of planning and spatial development, derived from the need to find a neutral term not directly connected with the actual planning system of any of the European Union (EU) member states. Williams calls it a *Euroenglish* word, due to its non-British origin, having resulted from the translation of the German *Raumplanung* and the Dutch *Ruimtelijk*.

One of the earliest definitions of spatial planning can be found in the European Regional/Spatial Planning Charter (Council of Europe, 1983), which states: "Regional/spatial planning gives geographical expression to the economic, social, cultural and ecological policies of society. It is at the same time a scientific discipline, an administrative technique and a policy developed as an interdisciplinary and comprehensive approach directed towards a balanced regional development and the physical organisation of space according to an overall strategy."

The Charter also states that “man and his well-being as well as his interaction with the environment are the central concern of regional/spatial planning” and that it should be its aim to “provide each individual with an environment and quality of life conducive to the development of his personality in surroundings planned on a human scale”. Moreover, it points at the need for harmonisation between the different interests at play in the territory, essential to achieve the spatial planning objectives of balanced socio-economic development of the regions, improvement of quality of life, rational use of land, and responsible management of natural resources and protection of the environment. According to the Charter, spatial planning should be:

> - Democratic: it should be conducted in such a way as to ensure the participation of the people concerned and their political representatives;
> - Comprehensive: it should ensure the co-ordination of the various sectoral policies and integrate them in an overall approach;
> - Functional: it needs to take account of the existence of regional consciousness based on common values, culture and interests sometimes crossing administrative and territorial boundaries, while taking account of the institutional arrangements of the different countries;
> - Long-term oriented: it should analyse and take into consideration the long-term trends and developments of economic, social, cultural, ecological and environmental phenomena and interventions.

A complementary definition is given later in the EU Compendium of Spatial Planning Systems and Policies (European Commission, 1997) which states that: “Spatial planning refers to the methods used largely by the public sector to influence the future distribution of activities in space. It is undertaken with the aims of creating a more rational territorial organisation of land uses and the linkages between them, to balance demands for development with the need to protect the environment, and to achieve social and economic objectives.”

Still, according to the Compendium, “spatial planning embraces measures to co-ordinate the spatial impacts of other sectoral policies, to achieve a more even distribution of economic development between regions than would otherwise be created by market forces, and to regulate the conversion of land and property uses", and “encompasses elements of national and transnational planning, regional policy, regional planning and detailed land use planning”.

Spatial planning is, in the end, a broad term that intends to comprise the entire science or discipline dealing with territorial organisation strategies and development goals, ultimately helping to foster dialogue between different traditions of spatial organisation and development. The term may have had its origins in the EU but, owing to the globally recognised importance of the territory in sustainable development and socio-economic cohesion, it is now used worldwide.

The phenomenon of urban growth, translated not only into urban densification but also into urban sprawl, together with the trend for monocultures in both agricultural and forestry production, resulted in a clash of interests that is difficult to manage and showed that environmental and cultural values are particularly vulnerable and in need of special attention.

The term conservation planning refers to planning with the intent of preservation — in other words, to the idea of wise use; it is ultimately an exercise on setting priorities, due to the infeasibility of applying conservation initiatives everywhere and simultaneously (Trombulak, 2010). Depending on the country and context where it is used, it may result in different definitions. There are two main trends when referring to conservation planning: the cultural line and the natural resources line.

In the United Kingdom, conservation planning is mainly employed in the field of heritage conservation: “At its very simplest, a Conservation Plan is a document which states why a place is significant and what policies there are to ensure that significance is retained. It is basically an archaeological and historical assessment of a building or site which has been taken one step further, so the understanding is translated into specific policies for caring for what is important about the site” (Clark, 1998).

On the other hand, the Natural Resources Conservation Service of the United States Department of Agriculture (United States Department of Agriculture, 2015) employs the term in regards to natural resources conservation: “A conservation plan is the record of decisions and supporting information for treatment of a unit of land meeting planning criteria for one or more identified natural resource concerns as a result of the planning process.”

Even though several terms are used to refer to one or another facet of conservation, cultural heritage conservation and habitat conservation are some of the most recognisable. Both are important and often intertwined, not mutually exclusive in real word scenarios.

This work focuses on natural resources conservation planning, mainly in biodiversity conservation. In particular, we look at conservation priorities in the face of resources constrains. We recognise conservation planning as being "concerned with societal activities to protect productive ecological systems, conserve native biological diversity and associated ecological and evolutionary processes, and maintain wild species of special interest. Conservation includes a diverse array of policy and management approaches (e.g., zoning, *ex-situ* and *in-situ* nature reserves, conservation easements, adaptive ecosystem management) and engages a wide range of disciplinary perspectives. Interdisciplinary research in systematic conservation planning is concerned with theory and techniques to improve the scientific basis of planning and the cost-effectiveness of conservation and management actions" (Halpern & Airamé, 2015)

2.2 History of planning and conservation

It is often thought that spatial planning and conservation are topics that only recently came together. In fact, that could not be further from the truth: there seems to be a long history of partnership and mutual development, strongly anchored in the evolution of the human perception of the world around us.

Although the majority of olden settlements might look too chaotic and organic for us to consider the existence of any form of spatial planning, studies have shown that they were everything but casuistically started, instead following a logic of proximity to resources, defence advantages, trade opportunities, shelter against natural hazards, and aspect benefits (Internet Geography, 2010). People lived in and of the land and, by observation, experience, and knowledge transmission, made use of it according to their needs and what they perceived would maximise their odds of surviving.

Organic growth was and continued to be the dominant system for a long time. However, where settlements began to densify, the need arose for some kind of concrete planning to support population development.

Since the pre-Classic and Classic periods, a number of cities started to be laid out according to fixed plans. Archaeologist believe ancient cities like Harappa, Lothal, Dholavira, and Mohenjo-Daro, in the Indus Valley Civilisation, were planned to included not only a hierarchy of streets, but also wells and drainage systems (Davreu, 1978; Kipfer, 2000). The same concern has also been identified in Mesoamerica (Smith, 2005).

Nevertheless, it was defence that, throughout the Classic and Medieval periods, played the most significant role in planning, with the recognisable gridded and walled Roman settlements, and later the more organic-growing but also fortified cities of medieval Europe (Kostof, 1999).

It was also early in history that man started to set aside natural areas deemed worthy of protection. From Asia to Europe and Africa, this practice was intrinsically connected with religion, the sense of holiness and the divine rights attributed to nobility. Sacred groves and trees were revered, and grand patches of forest were restricted, only to be used as hunting grounds for those born into nobility (Kanowski, Gilmour, Margules, & Potter, 1999).

The Industrial Age marked a turning point for both planning and conservation. A new dynamic of social classes emerged, and new disciplines and technologies changed how people viewed the world, allowing them to travel faster and to explore new places and resources. A rural exodus occurred, with masses of people heading towards the cities, which quickly grew and became dense and disorganised, turning into atrocious spaces riddled with pollution, crime, and disease.

The 17th century witnessed the invention of the microscope and the subsequent discovery of the cell, along with other substantial developments in the natural sciences. It also saw the birth of a new conscience of social sciences that originated with the utopic ideas of the Enlightenment. These innovations were of key relevance to the development of planning and conservation as we know it (Magalhães, 2001).

While the 18th century was marked by a growing awareness of social and environmental problems related to the rise of population in cities (Magalhães, 2001) and by the increasing interest in natural history, with grand expeditions being sent all over the world and public displays being organised by the thousands in both Europe and North America (Farber, 2000), the concept of conservation was far from established. At the time, fascination with endangered species translated into naturalists' goals of being the first to gather rare species before they were driven to extinction by other collectors, destroying hundreds of specimens in the process of completing collections (Evans, 1992; Farber, 2000).

With the arrival of the 19th century, the planning paradigm began to shift, as theorists got to work developing models to mitigate the consequences of the Industrial Age. The classic planning school, with origins in the utopic ideal city and developing alongside with sanitary movement (1800 — 1890), became particularly known for the garden city movement (Hall, 2014).

By the second half of the 19th century, social views had changed, and with them both planning and conservation. Rational planning emerged, establishing itself as the planning model of modernism. This movement emphasised the improvement of the built environment and advocated the supremacy of function over form, the separation of functions, the flow of vehicular traffic, and the standardisation of housing units, while maintaining the hygienist principles from classic planning, which defended direct sunlight exposure and proximity to green spaces (Hall, 2014; Skroblies, 2003).

The rational plan issued from a restricted group of specialists that employed logic, rationality, and their scientific knowledge to obtain the perfect final plan (Skroblies, 2003). Rationalist planners believed a good project to be universal and fit to be deployed anywhere in the world.

In conservation, preservationist and conservationist ideas had developed building on three core principles: that human activity was damaging to the environment, that there was a civic duty to protect nature for future generations, and that scientific and empirical methods should be applied to carry out this duty (Stebbing, 1922).

As conservation principles began to be put into practice, national parks started to emerge, spearheaded by the Yellowstone National Park in the United States. Early legislation regarding conservation was published and the first nature conservation societies founded (Baeyens & Martínez, 2004; Haines, 1996; Stebbing, 1922) . The term “conservation” started to be used not only as related to the preservation of forests, wildlife, parkland, wilderness, and watersheds but also to the management of natural resources such as timber, fish, game, topsoil, pastureland, and minerals (Baeyens & Martínez, 2004).

By the late 20th century, rational planning was in decline, and technocracy had alienated the public that it had hoped to serve (Allmendinger, 2005). Form followed by function and the universality of a good project were contested by the understanding of the territory as a complex system, composed by human and natural systems alike, and rationality was revealing itself too rigid to adapt to a time of fast paced change.

In this context, a new paradigm emerged, based on the idea that planning must be strategic, collaborative and resilient. This new paradigm sees the territory as a complex system with inner strengths and shortcomings, affected by forces both from within and without, competing with other territories. It focuses on actions to achieve development goals and emphasises the need to involve stakeholders in creating adaptable spaces, capable of reinventing themselves (Saboya, 2008).

In 1987, the Brundtland Report (World Commission on Environment and Development, 1987) defined sustainable development as follows:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:
>
> - The concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and
> - The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.
>
> Spatial planning starts to be seen as fundamental for this sustainable development, aiming for social-economic territorial cohesion and for the preservation of natural resources and human heritage (European Commission, 1999).

At the same time, the reduction in biodiversity had assumed proportions never before seen by the human race, becoming a major concern among the population and bringing the subject to the political agenda, which resulted in increased production of environmental laws, hastening of natural reserve creation, and unprecedented international cooperation between countries (Ministério do Ambiente e do Ordenamento do Território, 2001).

Since then, there has been a significant increase in the perceived importance of spatial planning and the need to include the population in the process of territorial decision. The development of new tools and techniques to help decision making is seen as crucial, going hand in hand with advances in computation, information, modelling, and visualisation technologies (Pinto, Lancrenon, & Berchtold, 2013).

In conservation, the need for implementation of comprehensive management measures throughout the landscape — as a complement to reserves and protected areas — has gained acceptance. Spatial planning started to incorporate green corridors and ecological networks, turning connectivity into the new paradigm of nature conservation in the 21st century (European Centre for Nature Conservation, 2010).

Unfortunately, even though protected areas are still steadily increasing (Figure 2), setbacks are starting to arise. Political and popular opinion around the subject seems to be changing for the worse, stemming from global economic slowdown, population growth, and lack of expected conservation results in many protected areas (Watson, Dudley, Segan, & Hockings, 2014).

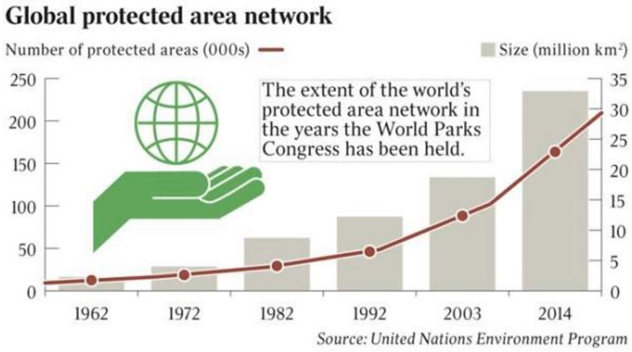
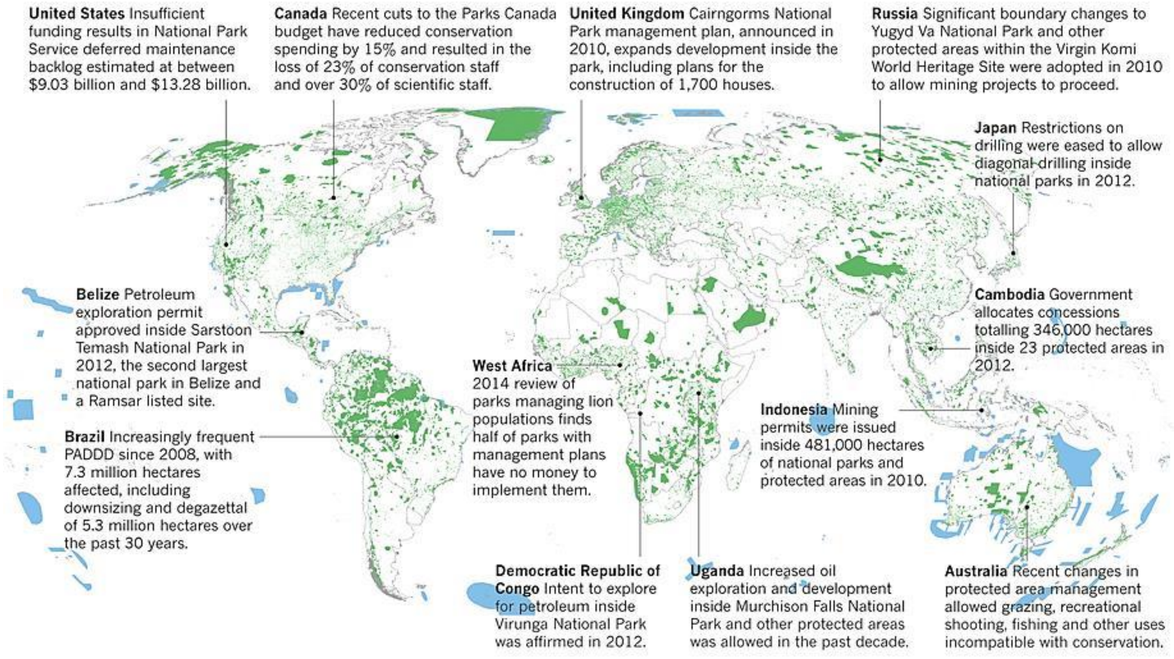


Figure 2: Global protected area network

As Figure 3 shows, we started experiencing some slackening and regress in environmental laws and a growing divestment in the maintenance of existing protected areas (Hannam, 2015; Mazza, 2015; Watson et al., 2014).

Still, studies show that biodiversity conservation and protected areas yield incalculable return, not only from the natural services and cultural values they provide but also through the economic activity they generate, directly and indirectly, via tourism and the safeguarding of valuable resource stocks (Balmford et al., 2015; Great Barrier Reef Marine Park Authority, 2014; Watson et al., 2014).



United States Insufficient funding results in National Park Service deferred maintenance backlog estimated at between $9.03 billion and $13.28 billion.

Canada Recent cuts to the Parks Canada budget have reduced conservation spending by 15% and resulted in the loss of 23% of conservation staff and over 30% of scientific staff.

United Kingdom Cairngorms National Park management plan, announced in 2010, expands development inside the park, including plans for the construction of 1,700 houses.

Russia Significant boundary changes to Yugyd Va National Park and other protected areas within the Virgin Komi World Heritage Site were adopted in 2010 to allow mining projects to proceed.

Japan Restrictions on drilling were eased to allow diagonal drilling inside national parks in 2012.

Belize Petroleum exploration permit approved inside Sarstoon Temash National Park in 2012, the second largest national park in Belize and a Ramsar listed site.

Cambodia Government allocates concessions totalling 346,000 hectares inside 23 protected areas in 2012.

West Africa 2014 review of parks managing lion populations finds half of parks with management plans have no money to implement them.

Indonesia Mining permits were issued inside 481,000 hectares of national parks and protected areas in 2010.

Brazil Increasingly frequent PADDD since 2008, with 7.3 million hectares affected, including downsizing and degazettal of 5.3 million hectares over the past 30 years.

Democratic Republic of Congo Intent to explore for petroleum inside Virunga National Park was affirmed in 2012.

Uganda Increased oil exploration and development inside Murchison Falls National Park and other protected areas was allowed in the past decade.

Australia Recent changes in protected area management allowed grazing, recreational shooting, fishing and other uses incompatible with conservation.

Figure 3: Regress and divestment in conservation around the world (Watson et al., 2014)

2.3 Main actors and forces in conservation planning

A multitude of interests affects the territory, creating a complex mesh of forces and actors that interact with and influence each other. The underlying actors are typically referred to as stakeholders and are composed by persons, groups, or institutions that have interests or can be affected by territorial decisions, actions, and policies.

Conservation planning stakeholder groups may be composed of scientists, planning technicians, affected individuals and communities, non-governmental groups like NGOs, or economic lobbying groups, governmental organisations, and government representatives.

Simplistically, one may cite ecological context, scientific knowledge, society, politics, and economy as the primary forces that affect conservation planning (Bixler, 2013; Escobar, 1998; Tear et al., 2005), (Figure 4). We will briefly look at each of these forces in the remainder of this section.

Ecological context encompasses the structure of the ecosystems, as well as their functional characteristics (Hanna & Munasinghe, 1995). It is in permanent evolution, the current context being the result of an historic line of past dynamics.

The cumulative ecological context through time affects current conditions and resource availability — and with it all forms of life that inhabit the territory and their behaviour. In what concerns other species, it often manifests itself in the degrees of diversity, unicity, intrinsic resilience, and inter-species interaction. In humans, it is known to impact culture and values, the way we look at and interact with the world (Pretty et al., 2008; Wiens & Donoghue, 2004).

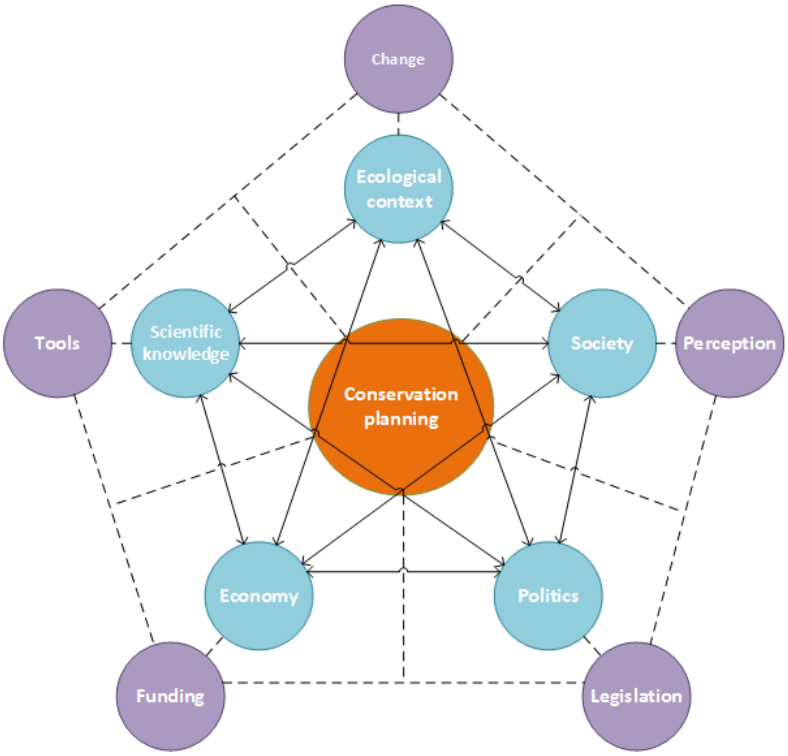


Figure 4: Dynamic of primary forces affecting conservation planning

Ecological context was often disregarded by humans, perceived as something constant and predictable, which is and always will be too big to fail or be affected by the human race. That perception has been progressively dispelled, with the ongoing destabilisation of natural systems becoming an increasing threat to human life and augmenting our awareness of the suffering of other species and of the need for action.

Scientific knowledge plays an important role in understanding the natural world, producing knowledge and tools that allow for the identification of needs and threats, helping to prioritise conservation goals and monitor those efforts. Scientific advances in the field have been outstanding, changing not only the way we see the natural world but also the way we look at anthropic phenomena.

It is often argued that conservation objectives must be solely dependent on sound fundamental science, insulated from social, economic, and political pressure, pushing their place to merely goal revision or implementation (Tear et al., 2005). Meanwhile, decision makers tend to focus on the degree of uncertainty present in all scientific production (Bradshaw & Borchers, 2000). The way uncertainty is treated and explained to stakeholders is important to facilitate dialogue and transparency, and can help promote political decisions based on scientific knowledge while avoiding the politicisation of science (Bradshaw & Borchers, 2000; Pielke, 2004).

Society, and its perception of a subject, can be the driver of — or a major impediment to — conservation planning and its implementation. Appreciation for conservation is determined by both internal and external factors; among the most obvious, we find:

- **Cultural ethics**: Moral values that dictate the way that a population interacts with other beings and the environment. For instance, according to Jainism, “all living things love their life, desire pleasure and are averse to pain; they dislike any injury to themselves; everybody is desirous of life and to every being, his own life is very dear”, leading its followers to adopt a vegetarian diet (Laidlaw, 1995).
- **Cultural affinity**: Bonds established throughout history between culture and particular species. For instance, European folklore, religion, and mythology depict wolves as dangerous and dark creatures, which impairs support towards its conservation (Boitani, 2000).
- **“Cute factor” and aesthetics**: Particular physical attributes possessed by species that cause certain reactions in people. For instance, a harp seal pup will have wider conservation support than a Dolloff cave spider (A. J. Knight, 2008).
- **Economic and utilitarian interest**: Particular cultural approaches to the management of species that are indispensable or have the potential to bring additional value to the anthropic way of life. For instance, the opposition to lower fishing quotas for sardines in Portugal (Hagemann, 2015).

Politics are the activities associated with the governance of a territory. In a democracy, political actions should reflect the will and interests of the majority, protecting their livelihood and promoting sustainable development. It is political will that commonly initiates conservation planning processes, manages the distribution of funds towards conservation, and engages in the creation of environmental legislation that translates into concrete measures reflecting societal values (Czech, Krausman, & Borkhataria, 1998). Legislation becomes an important provider of binding tools that not only support conservation priorities but also help to mediate and regulate different competing activities and opposing interests that greatly affect conservation planning (McHenry, 1993).

Economy is often seen only as an opposing force to conservation planning owing to its association with economic interests that lobby against conservation measures related to resource exploitation. But conservation planning is not free, and funding, both public and private, is fundamental for the implementation and maintenance of conservation measures. Funding also allows for more complete and elaborate scientific research, more comprehensive measures of conservation, and improved resolution of conflict resulting in a more favourable attitude towards conservation (Naidoo et al., 2006).

All these forces interact and influence each other, both positively and negatively, and their equilibrium is permanently being affected by anthropic framing, forcing compromises and precluding a one-size-fits-all methodology or solution. Maslow's hierarchy of needs dictates that conservation is unlikely to be a concern for poor communities until their basic needs are met, and only by improving conditions for the communities can we ever hope to achieve conservation goals.

Conservation planning requires initiative, either public or private; unfortunately, more often than not, it only happens in response to a significant change in the ecological context and in the perception of an existing problem. For the efforts to be effective, tools are required: scientific tools that help make better decisions, legal tools that help manage conflicts and produce consistent policies, and both scientific and legal tools that put the previous measures into practice while ensuring population needs are met and support is maintained.

2.4 Threats and costs in conservation planning

Biodiversity always has and always will be subjected to threats. In the past, most threats were of natural origins, with natural catastrophes often forcing species to adapt or perish. It is a recognised fact that human activity, in a combined and often unintended way, is now the main reason for the accelerated biodiversity loss.

The most significant anthropic sources of disturbances are well identified: pollution, habitat degradation/change, habitat loss, resource over-exploitation, diseases, alien species invasion, and, in an indirect way, climate change (Figure 5) (IUCN, 2007). As with the main forces affecting conservation, threats are intrinsically interconnected, mutually exacerbating the effects of one another in a downward spiral of negative feedback that impacts all species, including our own.

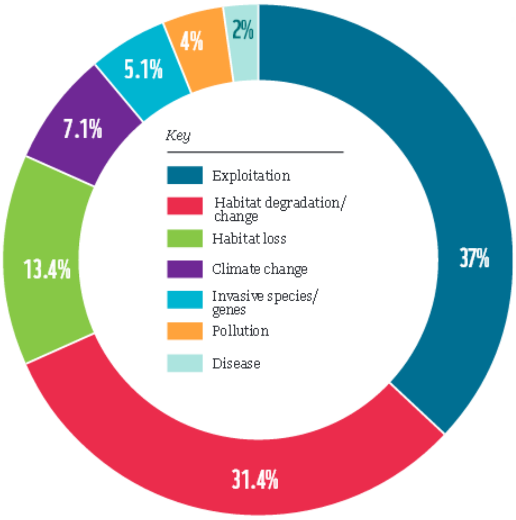


Figure 5: Primary threats to biodiversity (McLellan, 2014)

Conservation planning often aims to identify and diminish (or limit) the influence of these threats by trying to assess degrees of risk and imposing limitative measures on spatial use. In a world of limited resources, more and more relevance is given to the need to work around ecological problems and threats, keeping in mind a cost-benefit binominal.

There remains some controversy about what can be taken as a cost, especially when regarding immaterial concepts such as threats or political and societal trade-offs. Other types of cost, especially of the economic kind, are more notorious and consensual (Naidoo et al., 2006):

- **Acquisition costs:** related to acquiring property or use rights over a parcel of territory, often volatile and in line with the market
- **Management costs:** associated with the management of conservation, can be fixed operational costs or variable intervention costs
- **Transaction costs:** associated with the work surrounding acquisition of land, involving search, negotiation, legal fees, etc.

- **Damage costs:** associated with reparations to economic activities that arise from conservation programs, such as attacks to livestock or damage to crops
- **Opportunity costs:** associated with the loss of gains when compared to the next-best use

On the benefit side, studies are also focusing on the values of conservation and how they translate into economic terms. These benefits are denoted as ecosystem services and include provisioning, regulation, habitat support, and cultural amenities (de Groot, Alkemade, Braat, Hein, & Willemen, 2010).

Consensus on a coherent and integrated approach to ecosystem service assessment and valuation is still lacking, and most attempts are often admittedly undervalued. It is now widely recognised that nature conservation and conservation management strategies do not necessarily pose a trade-off between the environment and development, but can be complementary, generating ecological, social, and economic benefits (de Groot et al., 2010).

Beside the threats to biodiversity and ecosystems, we must also consider the threats and difficulties experienced by the conservation planning process in itself. These latter threats can also impose costs, not just monetary but also in the form of obstacles to the implementation and effectiveness of the plan.

Appropriate and effective communication is a major difficulty in conservation planning. Conservation planning, like most territorial sciences treating real-life phenomena with many dimensions, is too complex to be addressed through monodisciplinary approaches (Janssen & Goldsworthy, 1996). Conversely, multidisciplinary teams comprising different backgrounds often do not share the same norms, values, and vocabulary. This leads to confusion due to the use of terms with different meanings and to disagreements related to the relative importance of different phenomena (Janssen & Goldsworthy, 1996; Wear, 1999).

There are additional difficulties related to science–stakeholder communication. This dialogue, though profitable for both sides, is impeded by language and comprehension barriers, as well as dissimilar concerns and ways of looking at the conservation problem (Jönsson et al., 2014). Major breaks in communication are often an impediment to reaching balanced, consensual options that can be determinant for the implementation of a conservation plan. In recent years, research institutions have become increasingly involved in science-based stakeholder dialogue, despite the lack of a standard framework and the as of yet pending development of tools for the effect (Welp, de la Vega-Leinert, Stoll-Kleemann, & Jaeger, 2006).

Scale is another factor that affects conservation. There are several kinds of scales, of which some of the most influential are the biodiversity and government scales, closely connected with the spatial and temporal scales.

Biodiversity exists at many levels of biological organisation and occurs at a variety of spatial or geographic scales. Different species and ecosystems require different spatial specificities for their subsistence, influencing not only their resilience to change but also the resilience of all systems they integrate (Poiani, Richter, Anderson, & Richter, 2000). The usual information deficiency regarding both species and natural systems makes it hard to develop measures at the right spatial and temporal scales (Poiani et al., 2000).

The governance scale also creates difficulties in the planning conservation process. The patchwork of legislation and the lack of a clear framework for translating the objectives along the several administrative levels of government creates asymmetries and implementation lag that hinder the efficacy and efficiency of conservation measures (Paloniemi et al., 2012).

All the others notwithstanding, perhaps the single most recognised challenge to conservation planning nowadays is climate change and the uncertainty it entails. The growing instability in climate patterns is affecting both human activity and natural systems, changing land-use patterns, natural resource availability, species distribution, and ecological processes, and is expected to lead to significant biodiversity loss at a global level (Iwamura, Guisan, Wilson, & Possingham, 2013; Mawdsley, O'Malley, & Ojima, 2009).

The response of each species to climate change is highly specific: some will adapt and flourish, whereas others will dwindle to small refuges or simply disappear. The uncertainty surrounding the adaptive response of species and the extent of future climate change requires extra precautionary conservation measures contemplating not only the present situation but possible future developments (Mawdsley et al., 2009).

All of these delays, uncertainties, and misunderstandings are costly for conservation planning as a whole; they can result in unfavourable allocation of resources, defrauded expectations, and the burning of communication bridges for future conservation efforts.

2.5 Goals and targets in conservation planning

Conservation goals comprise one or more specific conservation results that a project intends to have on one or more conservation targets (Udelhoven, Neistein, Zurita, & Rice, 2012). Clear goals are indispensable for conservation planning: they facilitate the articulation of specific management objectives that translate to actionable targets with associated measures of success (Sound Science LLC, 2015).

Conservation targets are the biological attribute or value of the land that is the focus of a conservation project. It may include species, biological communities, ecological processes, or socio-ecological values; it may even include human features such as infrastructures, livelihoods, or commercial operations that may improve natural features (Sound Science LLC, 2015; Udelhoven et al., 2012).

The establishment of goals and targets in conservation planning is a complex problem, affected by numerous constrains and threats, often biased and lacking sufficient consistency and scientific rigour, leading to perplexing conservation objectives (Tear et al., 2005).

Many of the choices concerning goal and target setting have to do with the conservation approach adopted. Conservation planning approaches tend to be classified into proactive or reactive, the former focusing on acting beforehand to protect existing resources and attempting to protect high biodiversity areas that are still relatively unaffected by human activity, and the latter prioritising actions based on high vulnerability and immediate threats (Van Dyke, 2008).

There is a view among conservation biologists that general conservation goals should aim for:

- **Representativeness**: referring to the need to represent, or sample, the full variety of biodiversity, ideally at all levels of organisation (Margules & Pressey, 2000)
- **Persistence**: aiming to “promote the long-term survival of the species and other elements of biodiversity they contain by maintaining natural processes and viable populations and by excluding threats” (Margules & Pressey, 2000)

Representativeness is generally seen as related to species richness, that is, the number of different species represented in an ecological community, landscape, or region. Methods of operational research are often applied to optimise representation of a set of target taxa or habitat types (Kukkala & Moilanen, 2013).

Persistence, on the other hand, is often associated with rarity, looking at species that are restricted either in number or in area to a level that is demonstrably lower than the majority of other organisms of comparable taxonomic entities, putting them at a greater risk of extinction (Flather & Sieg, 2007). Most rarity approaches use data from the IUCN Red List (Figure 6 and Figure 7) (IUCN, 2015).

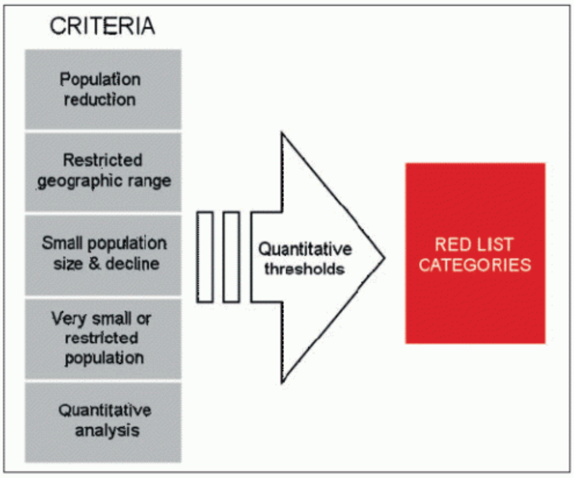


Figure 6: Criteria used for IUCN Red List categorisation (IUCN, 2015)

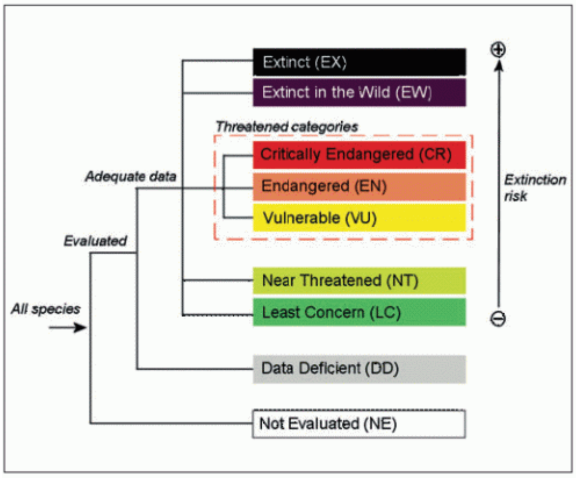


Figure 7: IUCN Red List categories (IUCN, 2015)

Often the resources are not sufficient for the full achievement of the two goals, forcing the prioritisation of one over the other, pitching conservation of areas with high diversity against areas with rare species at a high extinction risk. The legislation of most countries commonly benefits the latter option.

It is worth noting that a number of authors see the use of richness and rarity as obsolete terms in conservation planning, preferring to use instead irreplaceability and vulnerability (Brooks et al., 2006; Kukkala & Moilanen, 2013). We will, however, continue to use the referred terms for the sake of their recognisability to other stakeholders in the conservation planning process.

Traditional conservation goals and targets also frequently include design criteria, as well as concerns with connectivity, complementarity, minimum size, among others. These are of the utmost importance for the correct functioning of systems and the movement of species in the territory — and particularly for conservation area selection and the safeguard of important natural phenomena such as migrations (Margules & Pressey, 2000).

Finally, it is important to mention conservation goals and targets related to cost and other social-economic commitments and constrains. Conservation planning is often compatible with the development of complementary socio-economic development goals and targets (Naidoo et al., 2006). Activities such as tourism and outdoor practices that are certified as sustainable (adding value to products) have become socio-economic motors to the improvement of many communities.

The revised and updated Strategic Plan for Biodiversity for the 2011-2020 period (CBD Secretariat, 2015), signed in Nagoya, provided a new global overarching framework on biodiversity, not only for the biodiversity-specific conventions but also for the broader United Nations System and all other partners engaged in biodiversity management and policy development.

This update created the new set of goals and targets to be achieved, best known as the Aichi Biodiversity Targets. The twenty Aichi Biodiversity Targets are organised around five main goals (Appendix 1). Perhaps the best-known of those targets is the increase in the percentage of protected area.

2.6 Evolution of methods for reserve selection

Even with the present recognition that many conservation goals require the management of whole landscapes, protected areas and natural reserves are still the cornerstones on which most regional conservation strategies are built; their role is to “separate elements of biodiversity from processes that threaten their existence in the wild. They must do this within the constraints imposed by large and rapidly increasing numbers of humans in many parts of the world and their attendant requirements for space, materials and waste disposal” (C. R. Margules & Pressey, 2000b).

The IUCN defines protected areas as clearly defined geographical spaces, recognised, dedicated, and managed through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values (IUCN, 2008). The term “protected area” also includes Marine Protected Areas (MPA), the boundaries of which include some area of ocean (United Nations Environment Programme, 2015).

These reserved areas, specifically protected and put aside for nature conservation, can be designated both by government institutions or private landowners, such as charities and research institutions. They are labelled under a range of different names depending on their size, objectives, degree of protection, and applicable national laws (IUCN, 2008). This means that national parks, natural parks, natural reserves, etc. might have different scales and degrees of protection depending on the country in which they are located.

The need for international recognised standards for defining protected areas and encourage conservation planning according to their management aims led to the development of the IUCN Protected Area Management Categories, which classify protected areas into six classes according to their management objectives, summarised in (Table 1) (United Nations Environment Programme, 2015). To apply to one, protected areas must have at least 75% (three-quarters) of the area dedicated to a specific management objective; other management purposes may occur in the 25% remaining if compatible with the primary objective of the protected area (IUCN, 2008).

Historically, the creation of reserves and protected areas has generally followed an *ad hoc* approach, based mostly on worth perception, opportunistic land availability, and reaction to destruction threats. Spaces were typically reserved for protection because they were perceived as important for desirable species or for their scenic, recreational, and cultural values. It was also often the case where a reserve was created opportunistically, out of inexpensive or undesirable patches of land (R. L. Pressey, 1994; Trombulak, 2010).

This *ad hoc* strategy, in use until recently, ended up being a double-edged sword. If on one hand it protected natural resources and species that otherwise would already be extinct, its low effectiveness in representing biodiversity and its inefficiency in achieving more comprehensive conservation goals mined the confidence in reserves and their conservation aptitude (R. L. Pressey, 1994; Trombulak, 2010).

Major advances in sciences like biogeography and conservation biology — together with the need to find a methodology for reserve selection based on scientific facts, which could justify and boost confidence in the areas selected for protection and often attacked by social and economic interests — led to the development of the systematic conservation planning methodology at the end of the 20th century (Kukkala & Moilanen, 2013; Margules & Pressey, 2000).

Table 1: IUCN Protected Area Management Categories (IUCN, 2008)

Category	Definition by management objectives
Category Ia **Strict Nature Reserve**	Protected areas that are strictly set aside to protect biodiversity and also possibly geological/geomorphological features, where human visitation, use, and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.
Category Ib **Wilderness Area**	Protected areas that are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.
Category II **National Park**	Large natural or near-natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational, and visitor opportunities.
Category III **Natural Monument or Feature**	Protected areas set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature, such as a cave, or even a living feature, such as an ancient grove. They are generally quite small and often have high visitor value.
Category IV **Habitat/Species Management Area**	Protected areas aiming to protect particular species or habitats and whose management reflects this priority. Many protected areas in this category will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement.
Category V **Protected Landscape/Seascape**	A protected area where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural, and scenic value, and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation as well as other values.
Category VI **Protected Area with Sustainable use of Natural Resources**	Protected areas that conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with conservation is seen as one of the main aims.

Systematic conservation planning aims to offer a framework for a structured multi-component stage-wise approach to prioritising and managing habitats deemed important for conservation, with feedback, revision, and reiteration at any stage (Margules & Sarkar, 2007; Sarkar & Illoldi-Range, 2010).

This new way of looking at reserves creation and the definition of conservation area, a term that has presently substituted “reserve” in systematic conservation planning speech, understands the importance of explicit goals, of local and broader context priorities, and of social, economic, and political imperatives that drastically modify what would be the scientific prescriptions (Margules & Sarkar, 2007; Sarkar & Illoldi-Range, 2010; Sarkar, 2014).

Over the last few decades, the systematic conservation planning framework has been developed by many scientific groups, creating new and updated work protocols, rendering them more complex and adding components (Sarkar & Illoldi-Range, 2010).

The first explicit framework for systematic conservation planning had six stages (Margules & Pressey, 2000) (Table 2). Later contributions were made by several other authors, mainly relating to the importance of stakeholder inclusion for socio-economic viability of real-world implementations. These additional contributions resulted in extended frameworks of eleven stages (Appendix 2) and, more recently, fourteen stages (Table 3) that still retain the core stages of the original approach (Robert L. Pressey & Bottrill, 2008; Sarkar & Illoldi-Range, 2010; Sarkar, 2014).

Table 2: First systematic conservation planning framework (Margules & Pressey, 2000)

Stages	Tasks and decisions
Compile data on the biodiversity of the planning region	• Review existing data and decide on which data sets are sufficiently consistent to serve as surrogates for biodiversity across the planning region • If time allows, collect new data to augment or replace some existing data sets • Collect information on the localities of species considered to be rare and/or threatened in the region, likely to be missed or under-represented in conservation areas selected only on the basis of land classes such as vegetation types
Identify conservation goals for the planning region	• Set overall conservation targets that aim to achieve **representativeness** and **persistence** goals • Set quantitative conservation targets for species, vegetation types or other features. That, although subjective, are valuable on account of their explicitness • Set quantitative targets for **minimum size, connectivity,** or other **design criteria** • Identify qualitative targets or preferences
Review existing conservation areas	• Measure the extent to which quantitative targets for representation and design have been achieved by existing conservation areas • Identify the imminence of threat, to under-represented features such as species or vegetation types, and the threats posed to areas that will be important in securing satisfactory design targets
Select additional conservation areas	• Regard established conservation areas as “constraints” or focal points for the design of an expanded system • Identify preliminary sets of new conservation areas for consideration as additions to established areas, taking into account **complementarity, irreplaceability, vulnerability and cost, commitments, and other social constrains**
Implement conservation actions	• Decide on the most appropriate or feasible form of management to be applied to individual areas • Decide on the relative timing of conservation management when resources are insufficient to implement the whole system in the short term
Maintain the required values of conservation areas	• Set conservation goals at the level of individual conservation areas, ideally acknowledging the particular values of the area in the context of the whole system. • Implement management actions and zoning in and around each area to achieve the goals • Monitor key indicators that reflect the success of management actions or zonings in achieving goals and modify management as required

The development of the systematic conservation framework and the treatment of its multi-component complexity have been strongly assisted by the simultaneous developments in information and communication technologies.

The huge improvements seen in computational capability allowed for better acquisition, organisation, and treatment of complex biological and territorial data. This made space for the development and use of decision support software tools incorporating algorithms specifically designed for solving planning problems (Sarkar & Illoldi-Range, 2010). There are numerous tools specialised in conservation decision support, of which two of the best known are Marxan (Ball, Possingham, & Watts, 2009) and Zonation (Moilanen et al., 2014); both will be described in greater detail in the next chapter.

Table 3: Fourteen-stage conservation planning framework (Sarkar & Frank, 2012)

Stages	Tasks and decisions
Choose and delimit planning region	• Precise geographical boundaries of the planning region should be explicitly discussed and chosen. The drawing of the boundaries (e.g. whether they are based on political or ecological criteria) may raise ethical issues.
Identify stakeholders	• Stakeholders include those who significantly affect or are affected by conservation plans, and have a legitimate stake in the outcome.
Compile and assess data	• Relevant biological, ecological, and socio-political data must be collected in a cost-effective manner.
Treat data and build models if necessary	• Data treatment through statistical analysis is often required. Modelling is needed when treatment is insufficient to produce spatial data on relevant biological and socio-political factors.
Identify and evaluate biodiversity constituents and surrogates	• Stakeholders identify biodiversity constituents, which requires discussion of normative commitments and surrogates that might be used as quantitative estimators of biodiversity constituents.
Set goals and targets	• Quantitative and qualitative targets for biodiversity representation must be set; other goals include spatial configuration of the conservation areas to enhance likelihood of persistence.
Review existing conservation areas	• Any existing conservation area network must be analysed to determine the extent to which it already satisfies the specified goals and targets.
Prioritise areas for conservation	• New areas must be prioritised to meet the goals and targets that were set earlier. The aim is to achieve adequate representation of all biodiversity features while satisfying other desired goals.
Assess biodiversity and site vulnerability	• Prioritised areas and relevant biodiversity features must be assessed for vulnerability according the amount of risk deemed acceptable.
Refine networks	• If sites are vulnerable, they may be excluded from nominal conservation area networks and the selection process may be reiterated.
Incorporate additional criteria, if necessary	• Additional criteria (biological, economic, cultural, etc.) may need to be incorporated using multi-criteria analysis to evaluate trade-offs.
Devise management plan	• Management plans must be developed taking into account local context and resource availability. Ethical issues that must be tackled include the satisfaction of all human interests.
Implement conservation plan	• The management plan must be implemented for conservation to work. Consultation with local stakeholders is imperative for both ethical and practical reasons.
Monitor plan performance	• The performance of the plan must be monitored to devise responses as necessary for adaptive management into the future.

3 Geographical Information Systems in Biodiversity Conservation

3.1 Geographical information systems in conservation

Geographic information systems are a broad subject area, encompassing all systems designed to capture, store, manipulate, integrate, analyse, manage, present, and share all types of spatial or geographical data (Cai, 2014).

The term is also employed to refer to the academic disciplines or professions working within the GIS sphere and to a number of technologies, processes, methods, and tools pertaining to it, being attached to many operations and applications related to decision making in fields as diverse as engineering, planning, management, transport/logistics, insurance, telecommunications, and business (Cai, 2014; Maliene, Grigonis, Palevičius, & Griffiths, 2011).

Over the last few decades, we have witnessed a number of technology innovations that helped propel GIS to the forefront of spatial and conservation decision-making:

- improved computational capability, allowing for better acquisition, organisation, and treatment of complex territorial data problems, and for the development of new specialised applications (Sarkar & Illoldi-Range, 2010)
- remarkable developments in remote sensing, offering new details on spatial surface and shedding new light into the comprehension of phenomena with territorial expression (Lillesand, Kiefer, & Chipman, 2014)
- pervasive georeferenced information sharing, leading to participatory and collective sensing, regarded as the new frontier in spatial data gathering and analysis (Sagl & Resch, 2014)

Nonetheless, perhaps the biggest reason behind the spread of GIS in the various fields of planning, including spatial planning and conservation planning, is their flexibility and inclusiveness, known for promoting multidisciplinarity and stakeholder communication.

The most recognised use of GIS is computerised and descriptive mapping, making traditional cartography more easily available, updatable, analysable, and combinable to create new and innovative formats and visualisations of georeferenced data. Maps of vegetation, soils, contours, and land ownership fall in this category and are extensively used in conservation and spatial planning (Noss, O'Connell, & Murphy, 1997).

Geographical information systems are also known for their use in prescriptive mapping. Prescriptive maps are built upon descriptive maps by developing geographically-based models of natural and human systems that can help planners understand the forces and threats at stake and better plan in regards to environmental protection and management (Noss et al., 1997).

Visualisations built on GIS provide more effective communication between scientists, planners, and major stakeholders, strongly impacting spatial and environmental decision-making. Although static maps are still the standard means used in conversation, the integration of collaborative and interactive visualisation systems with GIS is seen as the natural evolution to improve communication, conservation decisions, and environmental education (Buytaert et al., 2014).

Descriptive mapping and prescriptive mapping saw major developments with the advances in remote sensing technologies. The ability to obtain frequent territorial information from above, over great territorial extensions and without the need for physical contact or moving around of human and technical resources, allowed for new insights into territorial evolution of both environmental and social systems (Lillesand et al., 2014).

Among the data acquired in this fashion, time-referenced land use and habitat identification are between the most important and widely used for conservation purposes, making it possible not only to assess a snapshot of the ecological and anthropic distribution in order to inform spatial decisions but also to monitor the effects of those decisions.

The new insights into ecological risks and losses made possible by remote sensing fuelled the need for models capable of facilitating the understanding of environmental and biologic phenomena and their future tendencies.

Modelling is a scientific activity whose aim is to make a particular part or feature of the real world easier to understand, define, quantify, visualise, or simulate by referencing it to existing and usually commonly accepted knowledge (Cartwright, 1983; Hacking, 1983). Modelling usually requires great amounts of high quality data, especially when we talk about modelling complex environmental, biologic, and socio-economic phenomena that are indispensable for conservation prioritisation.

Species distribution modelling, which will be further explored in the next chapter, is considered one of the most relevant modelling techniques for conservation, on par with those that focus on threats to conservation, such as climate change, urban growth and sprawl, land-use, and landscape fragmentation. Also important are the sciences that focus on costs and benefits, for instance, environmental services and acquisition costs.

This growing need for data led to the creation of public datasets. The INSPIRE Directive, adopted be the European Union in May 2007, recognises the importance of data gathering and sharing and makes an effort to establish an infrastructure for spatial information in Europe, looking to support policies or activities that may have an impact on the environment (European Commission, 2007).

Initiatives like the INSPIRE Directive not only aim to better allocate resources for data creation and gathering but also to augment communication and transparency in spatial and conservation choices. Only with the appropriate spatial information and the depiction of the environment that it provides can we plan for sustainability in an intelligent and transparent way, maximising resources, avoiding conflict, and monitoring the resulting progress.

3.2 Species data and species distribution models

Models are a well-known and long-established tool, used in a number of different scientific and technical fields; according to the classic definition of Peter Haggett, they are "a simplified version of reality, built in order to demonstrate certain properties of reality", whereas Alain Rey defines them as a "system representing the essential structures of a reality" (Brunet, 2001).

The rise of statistical techniques and GIS has given a great push to the usage of models in both spatial planning and conservation planning, which often need to combine limited data gathered from multiple sources into a comprehensible representation of complex environmental and biological systems.

Knowledge of the ecological and geographic distribution of a species (realised and potential, present and future) and a better understanding of the ecological and evolutionary determinants of spatial patterns of biodiversity are becoming fundamental tools in the prevention of biodiversity loss and in the selection of adequate prioritisation measures.

Species distribution models (SDMs), otherwise known as ecological niche models (ENMs) (Figure 8), are the main tools used to derive spatially explicit predictions of environmental suitability for species (Guisan et al., 2013).

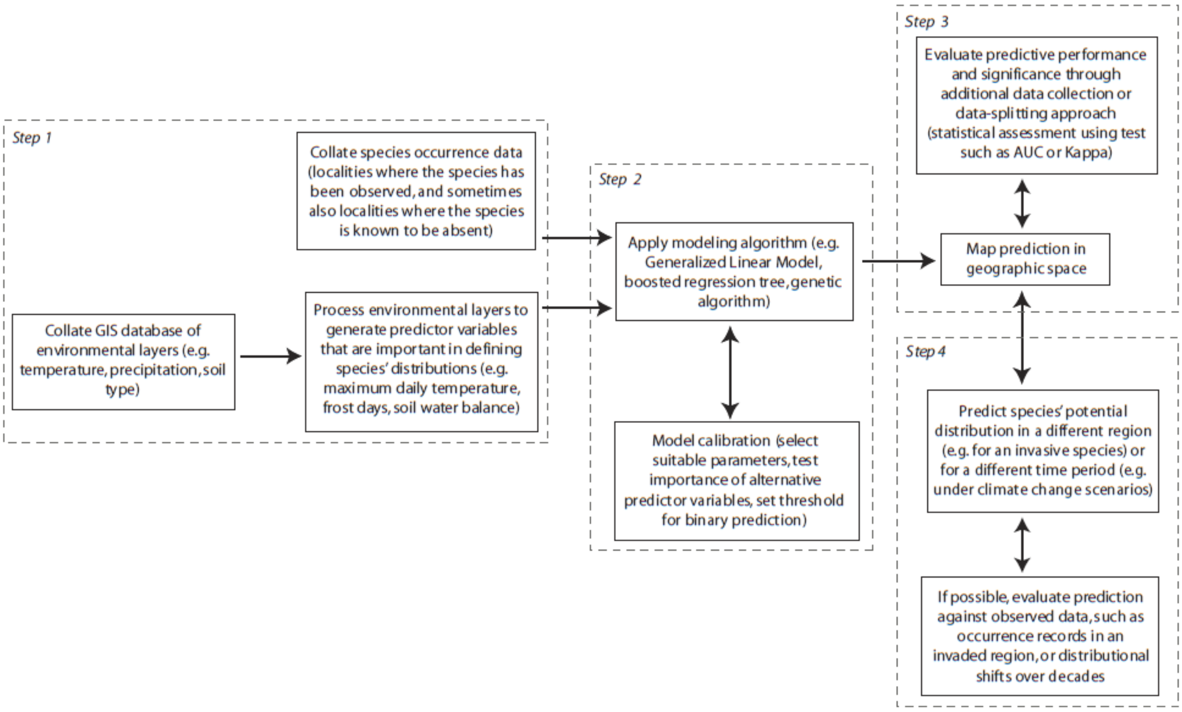


Figure 8: Steps of the ecological niche modelling process (Peterson et al., 2011)

Ecological niche models are empirical models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surfaces, outputting habitat suitability maps. This can be achieved by either a mechanistic or a correlative approach (Carvalho, 2010; Guisan & Thuiller, 2005).

Mechanistic models are designed to be realistic and general; they aim to incorporate physiologically limiting mechanisms in the definition of tolerance to environmental conditions. They are not judged primarily on predicted precision, but rather on the theoretical correctness of the predicted response, and require a detailed understanding of the physiological response of the species to environmental factors, making their use difficult for species that are not well studied (Carvalho, 2010; Guisan & Zimmermann, 2000).

Correlative SDMs are based on statistical or machine-learning tools that relate species data and environmental variables in order to predict the complete distribution of the species. They are currently the preferred approach and have been developing at an accelerated pace over the last two decades, with the emergence of several new statistical methods, evaluation procedures, and computational tools (Carvalho, 2010; Guisan & Zimmermann, 2000).

In the context of SDMs, environmental variables are generally optimally chosen to reflect the three main types of influences on the species (Guisan & Thuiller, 2005):

> - Limiting factors (or regulators), defined as factors controlling species eco-physiology (e.g. temperature, water, and soil composition)
> - Disturbances, defined as all types of perturbations affecting environmental systems (natural or human-induced)
> - Resources, defined as all compounds that can be assimilated by organisms (e.g. energy and water)

The differences between SDM methods are mainly the type of algorithms, output predictions, and occurrence data required, as well as their ability to predict uncertainty and assemble different solutions (Carvalho, 2010).

The species data used to build SDMs is generally based on random or stratified field sampling or observations obtained opportunistically, such as those in natural history collections (Guisan & Thuiller, 2005). Traditional types of data are (Guillera-Arroita et al., 2015):

- **Presence-background (PB) or presence-only (PO)**: data comprises only presence records of a non-exhaustive sample of true presences
- **Presence-absence (PA)**: data comprises information on whether a species was detected or not detected at a set of sampling sites
- **Occupancy-detection (DET)**: data comprises detection and non-detection records collected in such a way that the detection process can be explicitly modelled within the SDM, making use, for instance, of data from repeat visits to surveyed sites

Methods and tools such as ecological niche factor analysis (ENFA), BIOCLIM and DOMAIN require PO data and were developed to allow the use of data where knowledge of absences is inadequate or unavailable. They rely on the definition of environmental envelopes around locations where species occur, which are then compared to the environmental conditions of background areas (Brotons, Thuiller, Araújo, & Hirzel, 2004).

Conversely, methods and tools such as generalised linear models (GLM), generalised additive models (GAM), classification and regression trees, and artificial neural networks (ANN) require good quality PA data in order to generate statistical functions or discriminative rules that allow habitat suitability to be ranked according to distributions of presence and absence of species (Brotons et al., 2004).

Depending on the method or tools chosen, the habitat suitability maps generated by SDMs can be either a continuous probability of occurrence or a set of binary predictions. The former can be converted into binary through several methods of setting thresholds above which environmental conditions can be deemed suitable (Carvalho, 2010).

The potential of SDM-generated information for conservation planning is immense, as it can support most common steps of the systematic framework for conservation planning. They complement the very incomplete information about species range, help identify and access existing and future problems for conservation, and help define objectives and achievable targets for different situations (Guisan et al., 2013). In a latter section, we look at some of the factors that affect the quality of SDMs.

3.3 Programs and algorithms for reserve selection

Computational tools have become more and more relevant over the last few years, with a variety of software being developed to improve the process of informed decision-making and to support strategic decisions pertaining to environmental conservation in planning.

When we talk about conservation prioritisation and reserve selection, we generally refer to the design of networks of protected areas, formalised in two main classes of problems that can be solved by making use of heuristics, meta-heuristics, and optimal algorithms. These two classes of problems are known as (Carvalho, 2010):

- **Minimum set problem:** consists of finding the network with the minimum area or cost that meets all of the conservation targets, where often the objective is to minimise the total cost of selected sites while ensuring that each species is represented at or above a pre-determined target (Carvalho, 2010; Kreitler, Stoms, & Davis, 2014)

- **Maximum coverage problem:** searches for the network with the most conservation targets met at a specified budget; frequently the objective is to find a reserve system that contains the largest number of species meeting their targets, subject to a limit on the total cost of selected planning units (Carvalho, 2010; Kreitler et al., 2014)

Marxan is one of the best known conservation planning software packages. It was developed by Ian Ball, under the supervision of Hugh Possingham at the University of Adelaide, and solves the minimum set problem. The problem is translated mathematically in (Ball et al., 2009; Carvalho, 2010) by

$$minimize \sum_{i}^{N_s} x_i c_i + b \sum_{i}^{N_s} \sum_{h}^{N_s} x_i (1 - x_h) cv_{i,h}$$

Subject to the constraint that all the representation targets meet

$$\sum_{i}^{Nf} x_i r_{i,j} \geq T_j \,, \forall\, j$$

where variable $r_{i,j}$ is the occurrence level (for instance, abundance or number of populations) of feature j in planning unit i, and $x_i \in \{0,1\}$ is a control variable with value 1 for planning units selected in the set and value 0 for planning units that are not selected. The quantity c_i is the cost of planning unit i, N_s is the total number of planning units, N_f is the number of conservation features, T_j is the occurrence target of feature j, and b is the boundary multiplier that determines the cost of the overall selected planning units relative to the penalty of its spatial configuration. The matrix cv is the connectivity matrix, with elements $cv_{i,h}$ reflecting the cost of the connection (such as a boundary) shared by planning units i and h.

The real strength of Marxan is its implementation of a powerful metaheuristic algorithm, simulated annealing, that is able to generate good solutions to the minimum set problem in a relatively short amount of time (Game & Grantham, 2008).

The simulated annealing procedure runs for a user-defined number of iterations, and in each one a planning unit is randomly chosen. The algorithm calculates the change to the value of the objective function that would result from the planning unit being added or removed from the system, and uses a probability acceptance function dependent on a typically monotonically decreasing temperature parameter to decide whether the change should be accepted (Game & Grantham, 2008).

Our work, however, will focus on the maximum cover problem, and therefore we use Zonation, one of best-known software packages for this purpose.

Zonation is a conservation planning framework and software developed by Atte Moilanen and the Conservation Biology Informatics Group at the University of Helsinki. Already in its fourth version, it has been mainly used for identification of optimal reserve areas, identification of reserve area expansions, identification of areas for alternative land uses, target-based planning and management, and impact avoidance (Moilanen et al., 2014).

Zonation accepts a wide range of input data, both in grid and point format. Grids used as input need to be coincident, and can range from biodiversity features, such as species distribution data, to socio-economic data related to constrains that affect conservation, like cost and administrative units. Point data are mainly used to represent species of special interest (SSI), such as rare species for which there is insufficient data to build a model (Moilanen et al., 2014).

The software uses a gradient-like iterative heuristic algorithm that creates a hierarchical prioritisation of the landscape based on the occurrence levels of biodiversity features in sites (cells) by iteratively removing the least valuable remaining cell while accounting for connectivity and generalised complementarity. This algorithm is deterministic, as opposed to stochastic, implying that it finds the same result in all runs with the same settings and inputs (Di Minim, Veach, Lehtomäki, Pouzols, & Moilanen, 2011; Moilanen et al., 2014).

The algorithm used by Zonation is the same for all analyses. The order in which cells are removed depends on the cell removal rule that determines which one leads to the smallest marginal loss of value. There are four cell removal rules, which have specific characteristics that correspond to slightly different models of conservation preferences (Moilanen et al., 2014):

- **Core-**area **Zonation (CAZ)**: cell removal is done in a manner that minimises biological loss by picking the cell i that has the smallest δ, with

$$\delta_i = \max_j \frac{q_{ij} w_j}{c_i}$$

where δ_i is the minimum marginal loss of biological value, w_j is the weight (or priority) of species j, and c_i is the cost of adding cell i to the reserve network. The program goes through all cells and recalculates the δ_i after each removal. The value of each remaining cell goes up to retain core areas of all species until the cell removal process is completed, even if the species is initially widespread and common (Moilanen et al., 2014).

- **Additive benefit function (ABF)**: can be interpreted as the minimisation of aggregate extinction rates via feature-specific species-area curves, and the value of the cell removal index is simply a sum over species-specific declines in value following the loss of cell i:

$$\delta_i = \sum_j \Delta V_j = \sum_j \left[V_j\left(R_j(S)\right) - V_j\left(R_j(\{S-i\})\right) \right]$$

  where $R_j(S)$ is the representation of species j in the set of remaining sites S, and $\{S - i\}$ indicates the set of remaining cells minus cell i. V_j is some increasing function of representation for which typical alternatives include convex, sigmoid and ramp functions. The cells with the lowest δ_i are removed (Moilanen, 2007).

- **Target-based planning**: uses a very particular type of benefit function (Figure 9) that enables the process to converge to a solution that is close to the proportional coverage minimum-set solution for the data (Moilanen et al., 2014). The target-based value V_j is zero until representation R_j reaches the target T_j. Then, there is a step with height $(n + 1)$, where n is the number of features. When R_j increases above T_j and approaches 1, there is a convex increase in value with a difference $V_j(1) - V_j\left(T_j\right) = 1$. This means that the loss in value from dropping any one feature below the target is higher than any summed loss over multiple species that stay above the target (Moilanen et al., 2014).

- **Generalised benefit function**: operates like the ABF, but can take more flexible shapes, such as a sigmoid response (Figure 10 and Table 4).The function is defined by cases using two power functions (Moilanen et al., 2014):

$$V_j(R_j) = \begin{cases} w_1\left(\frac{R_j}{T_j}\right)^x & if\ R_j \leq T_J \\ w_1 + w_2\left(\frac{R_j - T_j}{1 - T_j}\right)^y & if\ T_j < R_j < 1 \end{cases}$$

Random cell removal can also be used, for instance, to compare different methods and their prioritisation effectiveness or to get a baseline representation level (Moilanen et al., 2014).

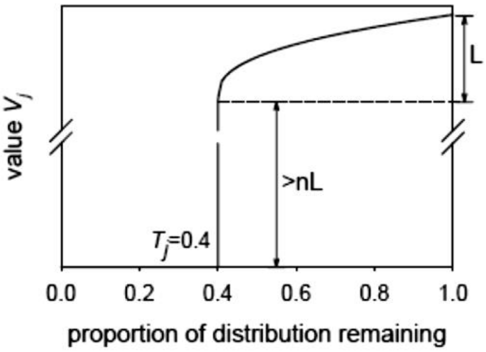


Figure 9: Zonation target-based function (Moilanen et al., 2014)

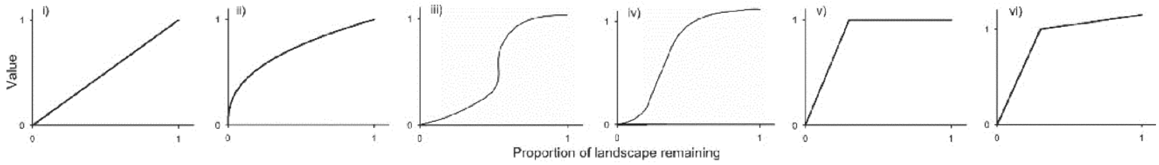


Figure 10: Generalised benefit function shapes (Moilanen et al., 2014)

Table 4: Generalised benefit function parameters (Moilanen et al., 2014)

		w_1	w_2	T_j	x	Y
i	Linear	w_j	0	1.0	1.0	NA, dummy=1.0
ii	Power function (=ABF)	w_j	0	1.0	<1 or >1	NA, dummy=1.0
iii	Mild sigmoid	w_j	same order as w_j	at inclination point	>1	<1, e.g. 1/x
iv	Steep sigmoid step imitation	w_j	same order as w_j	at step	>>1	<<1, e.g. 1/x
v	Ramp	w_j	0	at step	1.0	NA, dummy=1.0
vi	Ramp, with linear over-representation	w_j	<< w_j	at step	1.0	1

Of these cell removal methods, the most commonly used are CAZ and ABF (see Figure 11 for an example of operation). While the former has the capacity to identify a species-poor location where a single or a few biodiversity features are particularly important — leading to a tendency to protect rarity —, the latter gives more weight to biodiversity richness. Running both analyses might be important to reveal further relevant information for conservation (Moilanen et al., 2014).

It is worth noting that Zonation allows for the species/feature weights to be adjusted, which in turn allows for extra elasticity for the analyses, making it possible to add value to rare or protected species and to assign negative value to unwanted features, such as invasive species.

Zonation also provides a considerable set of options concerning reserve network aggregation design (Table 5), which is especially important since habitat fragmentation and human constructed barriers are known to be a challenge for biodiversity conservation. There is a variety of possible settings, whose configuration depends on conservation targets and input data (Moilanen et al., 2014).

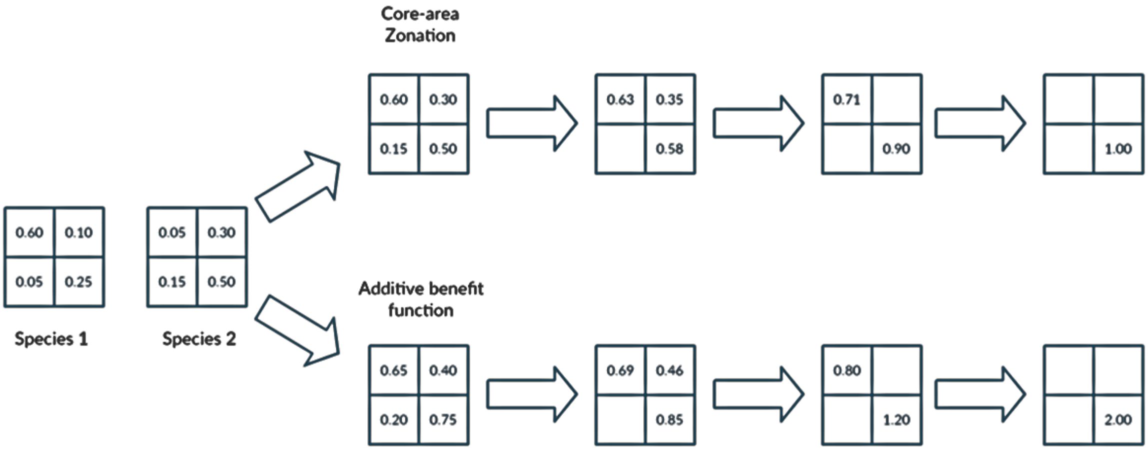


Figure 11: Cell remover in action: CAZ vs ABF (Loyola, 2013)

The program generates a number of different output files for each run, some automatic, others optional. Among the most important are the hierarchical priority rank map and the performance curves generated during the prioritisation process, which give extra information regarding (a) the cost curve and the proportion of distribution remaining across features, (b) the extinction risk of biodiversity features, and (c) the proportion of distribution remaining for SSI features as landscape is removed (Di Minim et al., 2011).

Zonation also supports other types of analyses, such as uncertainty analysis for robust conservation decisions, combined ecosystem-level and species-level analysis, and landscape condition and retention analysis, as well as balancing needs of alternative land uses and prioritising differently across multiple administrative regions. This makes it a very versatile software for which new potential uses are often identified (Moilanen et al., 2014).

Table 5: Zonation v4 aggregation methods (Moilanen et al., 2014)

Aggregation Methods	Characteristics
Boundary Length Penalty	• Commonly used for planning and management due to is computational efficiency • Uses a penalty on a structural characteristic of the reserve network (boundary length) to produce a more compact reserve network solution • Non-feature-specific aggregation method; might not be the most biologically realistic
Distribution Smoothing	• Feature (species)-specific aggregation method • Connectivity of cells is determined with a smoothing kernel, which means that the value of a cell is "smoothed" to the surrounding area • Computationally very quick, but assumes that fragmentation (low connectivity) is bad for all features and favours uniform areas over patchy ones
Boundary Quality Penalty (BQP)	• The most biologically realistic aggregation method included in Zonation • Based on feature-specific responses to neighbourhood habitat loss • Much longer computation time
Directed connectivity	• Generalisation of BQP where the connectivity between sites is strictly directed, such as in riverine systems • Demands use of planning units, groups of cells (rather than single cells) that are removed as a one during the landscape ranking process • The computation times are relative to the count (average size) of the planning units
Matrix connectivity	• Connectivity between multiple partially similar habitat types (or other linked entities) • The local occurrence level for each focal feature is multiplied by its connectivity to other features • Can be used to express preference for heterogeneous habitats, when a mixture of certain habitat types is more desirable than a homogeneous landscape
Edge removal feature	• This feature only allows cells to be removed from the edge of the remaining landscape • Can potentially create problems in the rare situation that a large area of poor habitat is completely surrounded by good habitat
Interaction connectivity	• Connectivity between a pair of features: can be positive or negative (e.g. symbiosis or prey-predator relation)
Corridors	• Corridor-like priority ranking

3.4 Error, uncertainty, and bias

The new systematic, computerised, and collaborative approach that is developing in conservation planning has brought with it advances that make the process more transparent and comprehensible. But difficulties still remain: errors and biases traverse the entire conservation process and impact the results obtained.

Biases are relevant error contributors to the systematic conservation planning process and often responsible for debatable priority conservation targets. In this case, we have to account for two types of bias: cognitive and statistical.

Cognitive bias is the deviation from rational judgment, generally subconscious and based on human perception, which often prevents objective consideration of an issue or situation (Hua, 2011). Cognitive bias affects the importance given to the preservation of different species, and with it conservation objectives and targets, scientific research funding, and the implementation of appropriate conservation (Iftekhar & Pannell, 2015; A. J. Knight, 2008).

Statistical bias, on the other hand, is a systematic deviation, typically resulting from the method and/or sampling employed in the creation and treatment of data. This bias affects the analyses of the current conditions of biodiversity features and future assessments of their development. It is said that, across Europe, there is a significant geographic, geopolitical, and taxonomic bias in data quality, distribution, and status. This is actually a global problem that affects biodiversity data and the datasets used in scientific analysis, including the Red List, influencing the weight given to some species in conservation planning (IUCN, 2012; Nieto & Alexander, 2010).

Geographic bias is a known problem that greatly affects species studies and the modelling of their distribution. Uneven collection efforts throughout the territories are generally explained by accessibility, with accessible places being significantly more sampled than those in areas that are difficult to reach. In other cases, preference is given to areas already considered of higher value, such as protected areas (Carvalho, 2010; Cayuela et al., 2009; Graham et al., 2008). This leads to some habitats and specific environmental situations being over-represented and others being under-represented, which in turn is conducive to omission errors (false absences) (Cayuela et al., 2009).

Geopolitics is also a relevant factor in data collection and quality. The inability to provide a strict but general rule for mapping taxa or habitats leads to the use of different methods and strategies, often aggravated by budget constraints and scale. Smaller and richer countries reveal proportionally higher data sampling and research attention, as opposed to larger and poorer countries (Cayuela et al., 2009; IUCN, 2012).

Taxonomic bias does not result solely from the preference given to some species over others. Some species are simply more easily measured than others, either from being constrained to a known small niche — as it the case for some rare endemic species — or from being more common, less shy, less mobile, living in more accessible places, or being more visible to the naked eye.

Adding to the bias that affect species data, we must also acknowledge that biodiversity data in use today has been collected throughout a long period of time and with different aims, such as the discovery of new species, comprehensive museology collections, and, more recently, conservation and environmental quality assessment (Cayuela et al., 2009).

This non-systematic and frequently presence-only data entails additional problems, such as commission and spatial errors — caused by factors that include data entry errors in the transfer of data from field sheets to electronic databases —, aggravated by textual geographical location descriptions, rounding errors, low-resolution locations covering large areas, and failure to specify the geographical *datum* (Graham et al., 2008).

Errors of commission are false positives for the existence of a species, which in conservation planning have the particular adverse impact of potentially competing with more appropriate locations, wasting funds and contributing to the failure to achieve conservation targets (Carvalho, 2010).

Other errors are related to species identification and classification, unaccounted metapopulation dynamics involving stochastic extinction and recolonisation, or migration episodes (Carvalho, 2010; Graham et al., 2008; Guisan & Thuiller, 2005).

Many of these problems can be controlled or mitigated by optimal field sampling, which consists of a stratified survey that ensures a representative sampling of the whole environmental conditions in the study area and limits bias on data. Such design is costly and time-consuming but generates a presence/absence data set allowing for discrimination techniques to be efficiently used and providing the most interpretable and meaningful results of all the sampling techniques (Dessimoz, 2006; Guisan & Zimmermann, 2000).

Species data are not the only data used in species studies and distribution modelling that are responsible for the introduction of errors. In particular, maps derived from interpolations, calculations or combinations are less precise than the maps from which they originate (Guisan & Zimmermann, 2000).

Environmental data layers, such as bioclimatic maps, are generally created by elevation-sensitive spatial interpolation of climate station data, introducing uncertainty derived from interpolation errors, lack of a sufficient number of stations, and the fact that standard climate stations do not reveal biologically relevant microclimates. Similar problems can be found in geologic or soil information maps generated at very coarse resolution and often drawn up using vegetation as a delineation criterion (Guisan & Zimmermann, 2000).

The conversion between types of data (raster and vector), often needed for reasons of consistency and computation, is also known to introduce a certain degree of error and uncertainty in the information.

SDMs not only import many of the problems present on the species and environmental data but also add new uncertainties, resulting from biotic and algorithmic errors (Guisan & Thuiller, 2005; Hanspach, Kühn, Pompe, & Klotz, 2010).

Biotic errors appear when ecological parameters are omitted from the modelling framework and lead to an inaccurate description of the distribution of the species, meaning the environmental predictors chosen were not capable of including all environmental, ecological, and historical factors that affect species distributions, or could not avoid partial collinearity between variables (Guisan & Thuiller, 2005; Hanspach et al., 2010; Mateo, de la Estrella, Felicísimo, Muñoz, & Guisan, 2013).

Algorithmic errors are an artefact of the data-collection process and stem from limitations of the models, creating the need for carefully thought-out modelling strategies and algorithms that take into account the available type and quality of the input data and the goal of the study (Guisan & Thuiller, 2005; Mateo et al., 2013).

There are several holistic strategies — encompassing the entire course of data acquisition, treatment, and modelling — that focus not only on containing and diminishing errors but also on quantifying the uncertainty and helping understand its sources (Guisan & Thuiller, 2005).

Errors, uncertainties, and bias are part of the conservation planning process and, though undesirable, their presence should not be seen as a calamity or an excuse to not use data or technologies with great potential to aid in decision making. Instead, their existence must be acknowledged, discussed, and potentially integrated as a cost in the conservation planning process. Their existence should be seen as a motivation to make the process increasingly more transparent and intelligible to all the stakeholders.

4 Methodology

The methodology employed in this work will follow a hybrid approach that incorporates lessons from both spatial planning and systematic conservation planning. This methodology is adapted to an academic scenario of conservation prioritisation and comparison of the results obtained using different conservation objectives.

Synthetically, we can divide the framework employed in six main steps: objectives, identification, literature review, input data, conservation prioritisation, computation, and outcomes (Figure 12).

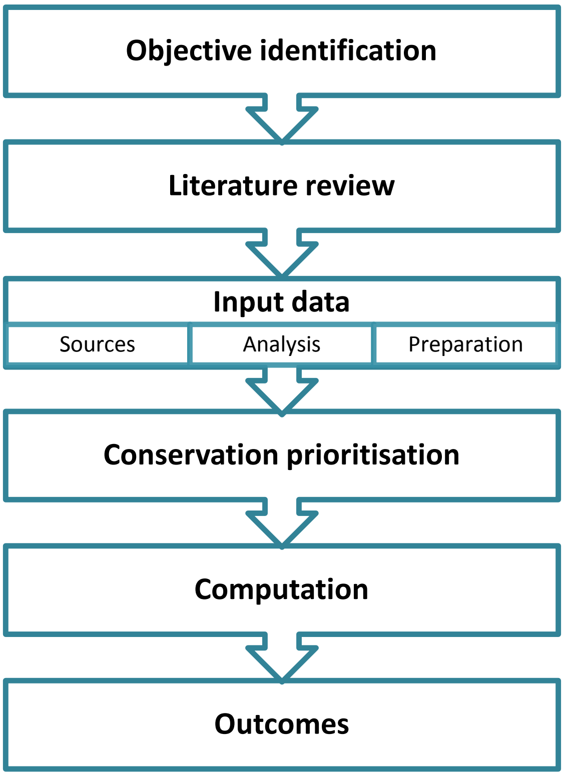


Figure 12: Methodology diagram

Objective identification, as the name implies, is the step in which the main objectives were traced. The objectives defined were mostly general: to identify high priority areas for conservation of biodiversity, to assess how these areas are affected by the type of information included in the evaluation, to appraise their concurrency or divergence from current protected areas, and to evaluate the advantages and disadvantages of decision support software such as Zonation v4.

Literature review was an important step to understand and better frame the subjects at hand. The multidisciplinary aspect of sustainable spatial decision and conservation planning made it necessary to conduct a broad review covering various areas of knowledge, including systematic conservation planning, spatial planning, GIS technologies, modelling, social sciences, and policy and legislation.

Following the literature review, the input data step was one of the most time consuming and complex, as seen in Figure 13. It can be divided in three stages: source, analysis, and preparation.

First, we gathered and assembled information and data pertaining to the thesis subject and specific study area. This information pertains to three main topics: biodiversity, socio-economics, and policy and legislation.

Under the biodiversity category we sourced information in the form of presence-absence data, habitat suitability maps generated from SDMs, and Red List status at the international, European, and national scales.

The socio-economic information acquired concerned sectors of activity, population density, land-use maps, and (partial) terrain acquisition costs.

Under policy and legislation, we procured protected area maps, collected popular vote records, and assembled a vast number of legislative documents concerning environmental protection and spatial planning, as well as published policies regarding future trends.

Data analysis consisted of the study of the information gathered. In this stage we assessed the quantity and quality of the data, identified information gaps, and obtained a new perspective by interrelating data. Among the most important analysis tasks we performed was the association of species with their Red List categorisation and legal status. We also undertook an info-gap analysis of the protected areas. This work took place in Zonation, and therefore used as input the data files resulting from the preparation step.

To complete the input data step, we proceeded to prepare the data to be processed by the computation software.

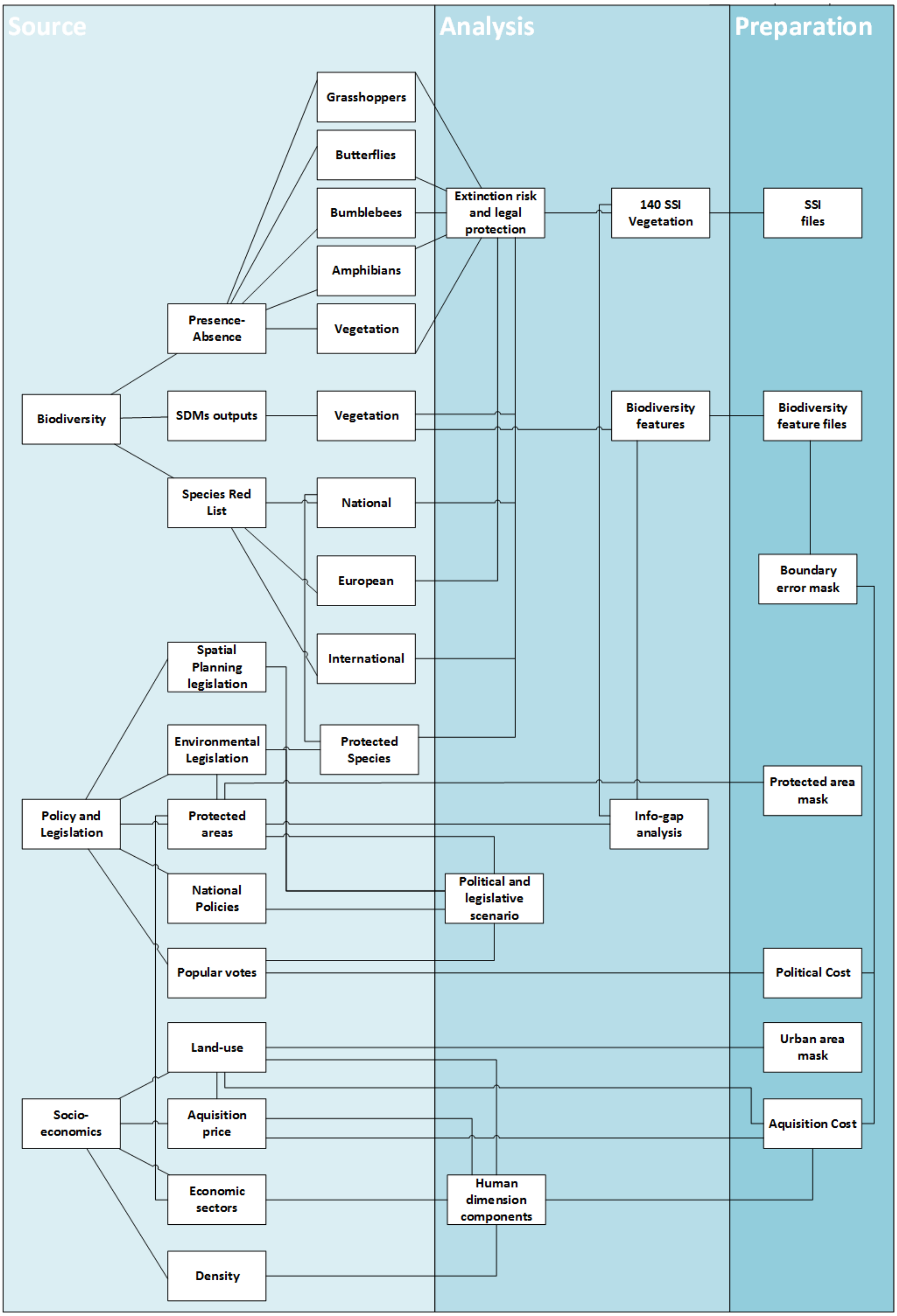


Figure 13: Input data methodology

Some of it was a fairly direct process, translating data and analysis results into the correct type of files readable by the program and creating appropriated files with the content of the analysis. This was the case for the files related with biodiversity features and SSI. Biodiversity features made use of the entire dataset of maps concerning habitat suitability for 279 vegetation species, which were converted into ASCII (list in Appendix 3). The relations identified (Red List and legal status) were used in the production of the necessary species lists and the assignment of weights.

For the SSI inputs, which make use of point data, and in the interest of consistency, we decided to use only information regarding vegetation, selecting only species under legal protection based on the previous relation analysis, resulting in a total of 140 species chosen (list in Appendix 4).

Other input files required more involved processes to bridge the existing gaps in the information, as was the case for terrain acquisition costs and political costs of conservation.

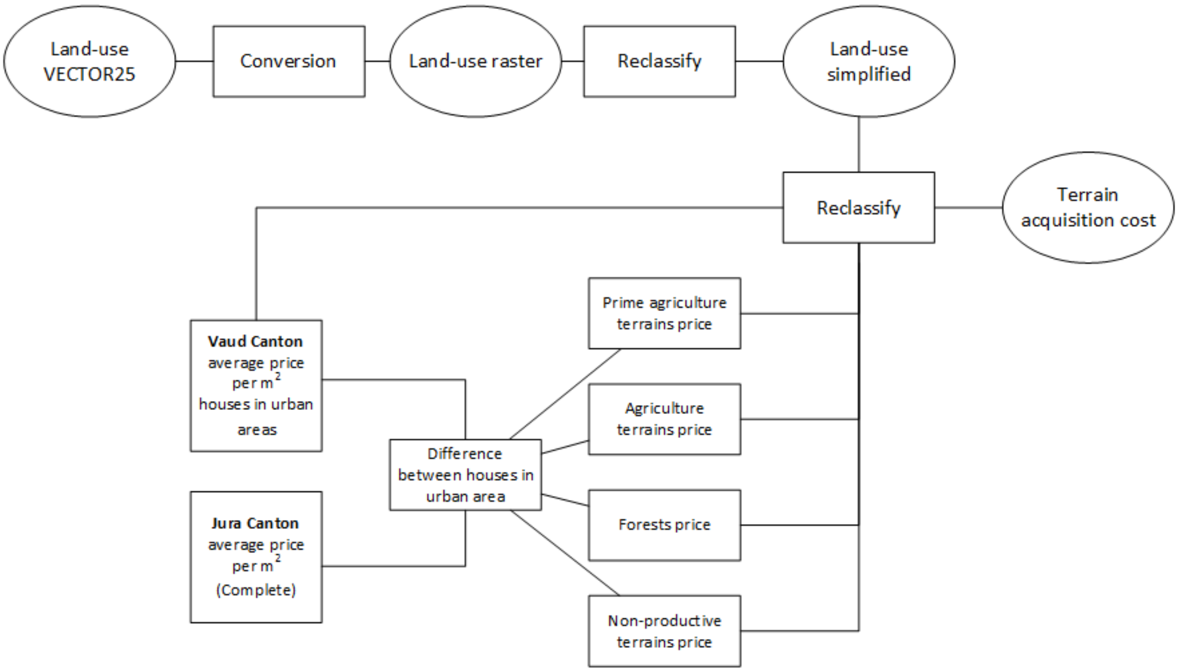


Figure 14: Terrain acquisition cost methodology

For the terrain acquisition cost, due to insufficient data for Vaud, we took the average price per square metre for houses in urban areas and for agricultural terrain in the Canton of Jura (for which we found complete data) and used the difference as a proxy to calculate appropriate prices for the other categories of land-use. Additional human context was used to reduce the VECTOR25 data to the same categories and, finally, the map was reclassified with the land price (Figure 14).

For the political cost, we identified the popular vote initiatives that could have a positive impact in biodiversity conservation, and reclassified the opposition voting percentage as political cost, all at the granularity of the commune (municipality), as depicted in Figure 15.

Both of this inputs were produced and assembled using the ArcGIS software.

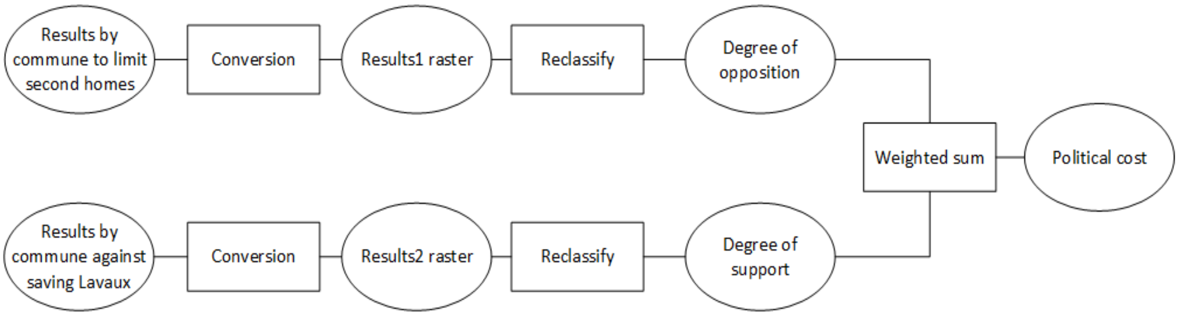


Figure 15: Political cost methodology

In the conservation prioritisation step, we defined and refined conservation objectives, now equipped with more solid knowledge and concrete data. As the most complete information on biodiversity features corresponded to vegetation, it made sense to shift the biodiversity conservation prioritisation analysis to the biodiversity of this group. The specific questions formulated were:

- How does species weighting affect prioritisation when we only take into account biodiversity features?
- Does the tendency to protect rarity versus richness greatly influence the results, and which is more coincident with the existing network of protected areas?
- Does the input of socio-economic factors affect site selection?
- Where are the top priority sites for the expansion of protected areas?

The computation step comprises the selection of the best methods to achieve a reply to the previously formulated questions, the creation of the appropriate configuration and batch files, and the actual computing time.

We followed a logic of always testing CAZ versus ABF, grouped in three topics: a group of eight analyses regarding species weighting, a group of eight analyses regarding other socio-economic costs, and a group of two analyses concerning protected area expansion. Table 6 shows the specific parameterization used in each run.

Finally, in the outcomes step, Zonation outputs were analysed using ArcGIS as a supporting platform, allowing us to draw conclusions both regarding the general objectives and the more refined ones.

Table 6: Zonation computation scenarios and parameters

Rarity versus richness and species weighting using only biodiversity		
Scenario	**AA1**	**AA2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	1	1
Biodiversity/SSI features quotient (x)	NA	0.25
Scenario	**AB1**	**AB2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6
Biodiversity/SSI features quotient (x)	NA	0.25
Scenario	**AC1**	**AC2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area curve	0.25	0.25
Biodiversity/SSI features weight	Based on Legal status Not protected = 1, Protected = 3	Based on Legal status Not protected = 1, Protected = 3
Biodiversity/SSI features quotient	NA	0.25
Scenario	**AD1**	**AD2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected
Biodiversity/SSI features quotient (x)	NA	0.25

Table 6: Zonation computation scenarios and parameters (continued)

Socio-economic data in the prioritisation process		
Scenario	**BA1**	**BA2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected
Biodiversity/SSI features quotient (x)	NA	0.25
Removal mask	Active: urban area	Active: urban area
Analysis area mask	Active: exclude boundary error	Active: exclude boundary error
Scenario	**BB1**	**BB2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected
Biodiversity/SSI features quotient (x)	NA	0.25
Removal mask	Active: urban area	Active: urban area
Analysis area mask	Active: exclude boundary error	Active: exclude boundary error
Use Costs	Active: acquisition cost	Active: acquisition cost
Scenario	**BC1**	**BC2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected
Biodiversity/SSI features quotient (x)	NA	0.25
Removal mask	Active: urban area	Active: urban area
Analysis area mask	Active: exclude boundary error	Active: exclude boundary error
Use Costs	Active: political cost	Active: political cost

Table 6: Zonation computation scenarios and parameters (continued)

Scenario	**BD1**	**BD2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected
Biodiversity/SSI features quotient (x)	NA	0.25
Removal mask	Active: urban area	Active: urban area
Analysis area mask	Active: exclude boundary error	Active: exclude boundary error
Use Costs	Active: acquisition cost and political cost	Active: acquisition cost and political cost
Comparing and expanding protected areas		
Scenario	**C1**	**C2**
Removal rule	CAZ	ABF
Warp factor	100 cells removed per iteration	100 cells removed per iteration
Edge removal	Active	Active
SSI	Active	Active
Exponent of the species area Curve (z)	0.25	0.25
Biodiversity/SSI features weight (w)	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected	Based on National Red List: DD=NE=LC=1, NT=2, VU=3, EN=4, CR=5, RE=6 And legal status: +2 if protected
Biodiversity/SSI features quotient (x)	NA	0.25
Removal mask	Active: urban area and protected areas block	Active: urban area and protected areas block
Analysis area mask	Active: exclude boundary error	Active: exclude boundary error
Use Costs	Active: acquisition cost and political cost	Active: acquisition cost and political cost

5 Conservation prioritisation in the Alpine region of Vaud

5.1 Geographical framing

The area of study chosen for this work is the Alpine region of the Canton of Vaud, in Switzerland, depicted in Figure 16 and Figure 17, which is the target of a transdisciplinary research platform called RechAlp[2] that aggregates information mainly in the area of natural sciences.

The study area covers a surface of roughly 700 km^2, covered by a heterogenic landscape that ranges from flatlands to high mountains, with elevation ranging from 375 to 3210 m.

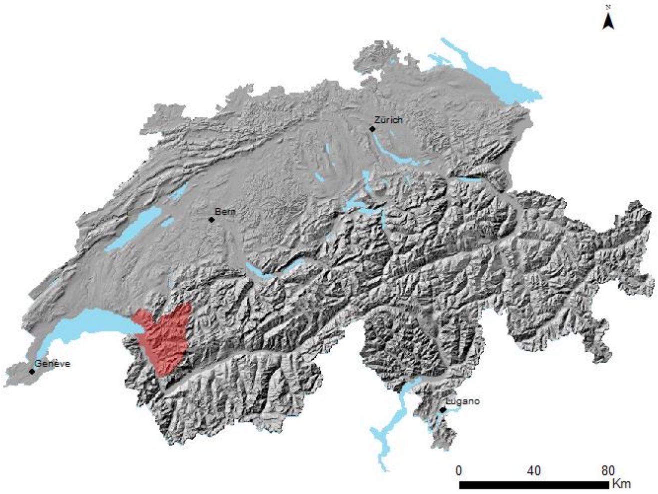


Figure 16: Study area in the context of Switzerland

Figure 17: Study area detail

The lowest areas, situated on the south-western edge of the study area, comprise a part of the Rhone Valley and are characterised by irrigable fertile land; the highest point, part of a snow-covered mountain, is the Diablerets Summit, which can be found close to the east edge of the study area. Middle range altitudes are characterised by a mix of forests, meadows, and pastures.

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[2] http://rechalpvd.unil.ch/

Temperature and precipitation are dependent on altitude and topography. Mean monthly temperatures vary between − 1 °C and − 5 °C during winter, and between 10 °C and 15 °C during summer, while mean precipitation ranges between 115 mm/month and 200 mm/month, often in the form of snow, especially at higher altitudes (Milano, Reynard, Köplin, & Weingartner, 2015).

The alpine river regimes in the study area are mostly dependent upon the snowmelt, which enhances flows predominantly in May and June (Milano et al., 2015). The snow that feeds the rivers and enriches the economy is also responsible for one of the most dangerous phenomena of the Alps, the avalanches; although they mostly follow well-defined paths, their occurrence is difficult to predict and they constitute an ever-present danger during a period extending from late November to early June (Diem, 2015).

5.2 Policy and legislation

5.2.1 Political system

Switzerland is a federalised republic and, for the most part, a direct democracy. It is considered one of the most stable and participatory democracies in the world. Governance is played on three levels — confederation, canton and commune —, each with prescribed powers and sources of income (Le Conseil Fédéral, 2015).

The powers of the confederation are vested by the Federal Constitution, which addresses concerns at the national level and includes some legislation regarding spatial planning, the environment, and conservation agreements done in an international context (Le Conseil Fédéral, 2015).

The cantons have a high level of autonomy; although they have equal status and rights, each has its own constitution, parliament, government, and courts. Cantonal parliaments are all elected by the people, the preferred system in most cantons being a system of proportional representation (Le Conseil Fédéral, 2015). Their high autonomy extends to the enforcement of environmental and planning laws, and allows each canton to complement them according to regional specificities.

Finally, the smallest governance unit are the communes. They are mostly autonomous, the largest ones having their own elected parliaments, and others reaching decisions in the direct-democratic forum of the communal assembly, in which all residents who are entitled to vote can participate (Le Conseil Fédéral, 2015). Communes are responsible for tasks related to local decisions and tasks delegated to them by the confederation and the cantons.

Governance follows a principle of subsidiarity where “nothing that can be done at a lower political level should be done at a higher political level. If, for example, a commune is unable to deal with a certain task, the next higher political level, i.e. the canton, has a duty to provide support” (Le Conseil Fédéral, 2015).

Referendums are part of everyday life, with Swiss people being called to cast their vote in a range of national, cantonal or communal issues three to four times a year. The results of these referendums are binding, being transposed to legislation at the government level at which the question was proposed.

This approach to democracy, with regular direct participation, not only gives extra power and a sense of involvement to the people but also presents us with a rare opportunity to assess cultural traits and trends, including trends that may affect conservation.

Over the last ten years, there have been at least two popular votes in our area of study for which the questions posed and the corresponding results might affect and imply views regarding conservation planning initiatives — and with it biodiversity conservation.

The oldest example in this period is the popular initiative voted in 2012 at the Federal level: "Pour en finir avec les constructions envahissantes de résidences secondaires"[3]. This initiative aimed to limit the number of secondary residences to a maximum of 20% of the habitational park, one of the reasons being the pressure exerted on the landscape by constructions that were only used as a weekend refuge. The initiative passed with the results shown in Figure 18.

A more recent initiative, "Sauver Lavaux"[4], was put to a vote in 2014 at the cantonal level. Voted along with a counter-initiative, it intended to increase the protection level on an already protected area known by its cultural and agricultural characteristics (Lavaux region). The counter-initiative won (Figure 19 presents the voting distribution), showing a preference of the majority for a more relaxed level of protection, with less limits to human activity.

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[3] “Stop the endless construction of second homes”

[4] “Save Lavaux”

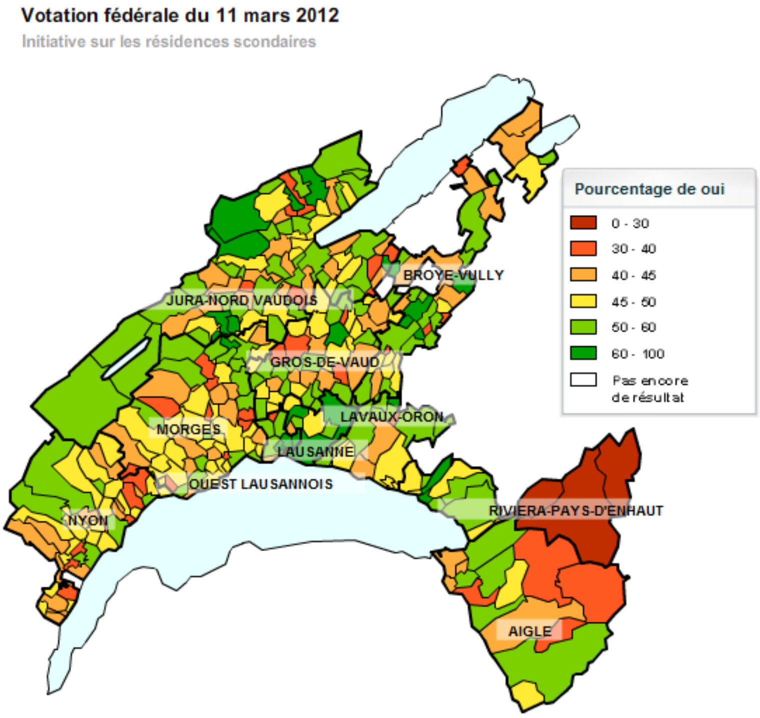

Figure 18: Cantonal results from the popular vote on the initiative "Pour en finir avec les construction envahissantes des résidences secondaires" (Canton de Vaud, 2015)

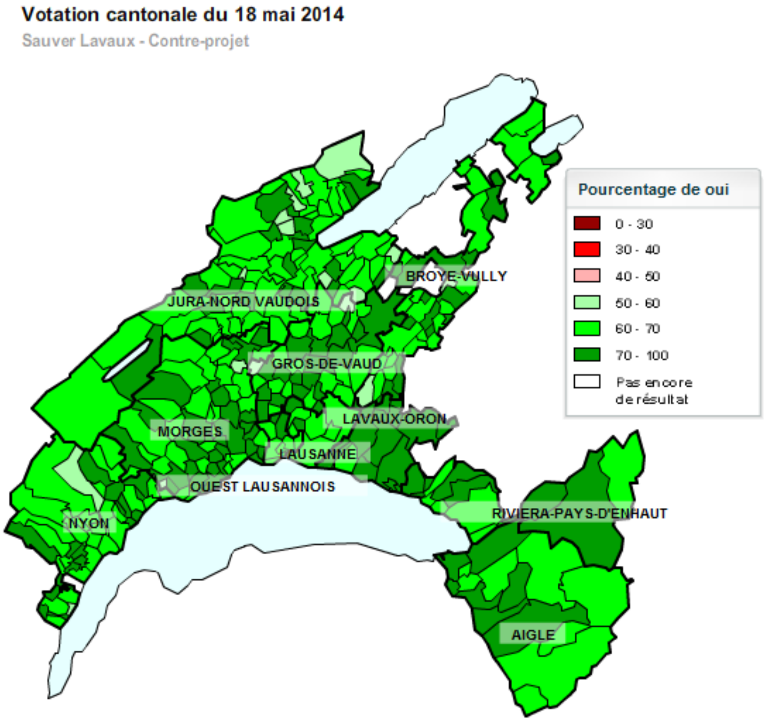

Figure 19: Cantonal results from the popular vote on the counter-initiative to "Sauver Lavaux" (Canton de Vaud, 2015)

We averaged the vote percentages in favour of the 2012 initiative with those against the 2014 counter-initiative. The result, presented in Figure 20 in the form of a map of study areas in the south-east of the canton, allows us to identify a trend. Communes in the north-east of the study area and a commune in the north-west of the Rhone Valley show tougher stances towards measures that constrict human activity to conservation purposes. These stances most likely imply stronger political costs and a different level of negotiation required to implement conservation measures, compared to other communes with lower opposition.

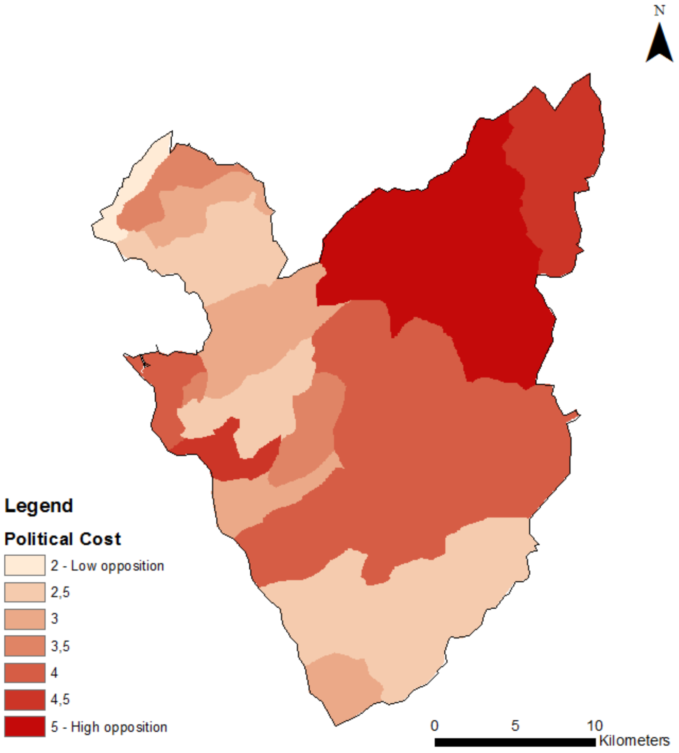

Figure 20: Potential political cost for conservation

5.2.2 Environmental and spatial legislation

The Swiss political and legislative system has several advantages, namely being one of the most participative in the world. However, due to its dynamism, legislation often seems somewhat disjointed, scattered around a vast number of documents at different levels of governance. This is clearly the case for environmental legislation, as evidenced by the summary of legal bases relevant to conservation planning in our study area (Table 7). Still, in spite of the complexity, the widespread culture of civil duty makes the system reasonably effective.

Starting from the highest level of governance, the Swiss constitution dedicates its Section 4 to the environment and to spatial planning. Over its seven articles, the major themes are the achievement of a balanced and sustainable relationship between nature and the demands placed on it by the population, and the protection of animal and plant life, their natural habitats, and their diversity, with special focus on preventing extinctions (*Constitution Fédérale de la Confédération Suisse*, 1999).

Table 7: Summary of legal bases relevant to conservation planning in our study area

Constitution fédérale [RS 101]
Section 4 Environnement et aménagement du territoire
Bases légales: biodiversité
Loi fédérale sur la protection de la nature et du paysage (LPN) [RS 451]
Loi sur la chasse (LChP) [RS 922.0]
Loi fédérale sur la pêche (LFSP) [RS 923.0]
Loi sur l'agriculture (LAgre) [RS 910.1]
Loi sur les forêts (Lfo) [RS 921.0]
Loi fédérale sur la circulation des espèces de faune et de flore protégées [RS 453]
Ordonnance sur la protection de la nature et du paysage (OPN) [RS 451.1]
Ordonnance sur la chasse (OChP) [RS 922.01]
Ordonnance relative à la loi fédérale sur la pêche (OLFP) [RS 923.01]
Ordonnance sur les hauts-marais [RS 451.32]
Ordonnance sur les bas-marais [RS 451.33]
Ordonnance sur les sites marécageux [RS 451.35]
Ordonnance sur les prairies sèches (OPPS) [RS 451.37]
Ordonnance sur les batraciens (OBat) [RS 451.34]
Ordonnance sur les zones alluviales [RS 451.31]
Ordonnance concernant les districts francs fédéraux (ODF) [RS 922.31]
Ordonnance sur les réserves d'oiseaux d'eau et de migrateurs d'importance nationale et internationale (OROEM) [RS 922.32]
Ordonnance sur les paiements directs (OPD) [RS 910.13]
Conventions internationales
Convention relative aux zones humides d'importance internationale particulièrement comme habitats des oiseaux d'eau (Convention de Ramsar) [RS 0.451.45]
Convention relative à la conservation de la vie sauvage et du milieu naturel de l'Europe (Convention de Berne) [RS 0.455]
Convention sur la conservation des espèces migratrices appartenant à la faune sauvage (Convention de Bonn) [RS 0.451.46]
Convention sur la protection des Alpes [RS 0.700.1]
Convention sur la diversité biologique [RS 0.451.43]
Bases légales: Canton Vaud
Règlement concernant la protection de la flore (RPF) [RS 453.11.1]
Bases légales: aménagement du territoire
Loi sur l'aménagement du territoire (LAT) [RS 700]
Ordonnance sur l'aménagement du territoire (OAT) [RS 700.1]
Ordonnance relative à l'étude de l'impact sur l'environnement (OEIE) [RS 814.011]
Ordonnance concernant l'inventaire fédéral des paysages, sites et monuments naturels (OIFP) [RS 451.11]
Ordonnance sur les parcs d'importance nationale [RS 451.36]

The constitution also delegates to the Cantons the main responsibility for protecting the natural and cultural heritage. This orientation is confirmed by laws in the environmental and spatial planning areas that attribute to the Cantons the powers to manage and plan human activity in the territory and the obligation to identify important areas for biodiversity and cultural heritage preservation (*Loi Fédérale sur la Protection de la Nature et du Paysage*, 1966) (*Loi Fédérale sur l'Aménagement du Territoire*, 1979).

Ordinary laws are the second level of federal legislative documents. They are less broad than the constitution, and detail definition, responsibilities, and processes. Most details are published in decrees that elaborate on the content of laws and implement international conventions.

The "Ordonnance sur la protection de la nature et du paysage"[5] (*Ordonnance sur la Protection de la Nature et du Paysage (OPN)*, 1991) is one of the decrees that interest us the most. Among its many subjects, it contains the entire list of nationally protected biotopes and species.

According to the legislation, protected species encompass not only rare species — those assigned to the extinction risk categories in the national Red List — but also a number of species that are low-risk but may be of cultural importance to the Swiss population.

There is one decree for each biotope that is considered in the biotope and landscape inventories of national importance. Each of these documents introduces limitations to human activity in those selected sites.

On the cantonal level, federal legislation is once again supplemented, in line with the natural and cultural specificities of each region. In Vaud, the main concern appears to be flora biodiversity, as these are the only species whose protection is complemented through cantonal regulations (*Règlement Concernant la Protection de la Flore*, 2005).

Overall, after an intensive review of the legislative documents concerning biodiversity conservation, it is difficult to diffuse the existence of a bias towards rarity over richness in natural features, while in spatial planning the focus on sustainable development seems to be mostly concerned with the avoidance of urban sprawls, directing urban development towards densification. Although they may be contested, both are common and valid prioritisation strategies.

5.2.3 Protected areas

The large extent of area marked for conservation, under a variety of programs, is a testimony to the biological and cultural relevance of our study area. Roughly 25% of the territory can be considered to be under a direct program of biodiversity conservation (Figure

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[5] Ordinance on the Protection of Nature and Cultural Heritage

21). If, to that, we add programs that preserve cultural landscapes and traditional ways of life, indirectly protecting biodiversity, the percentage rises to a notable 63% (Figure 22).

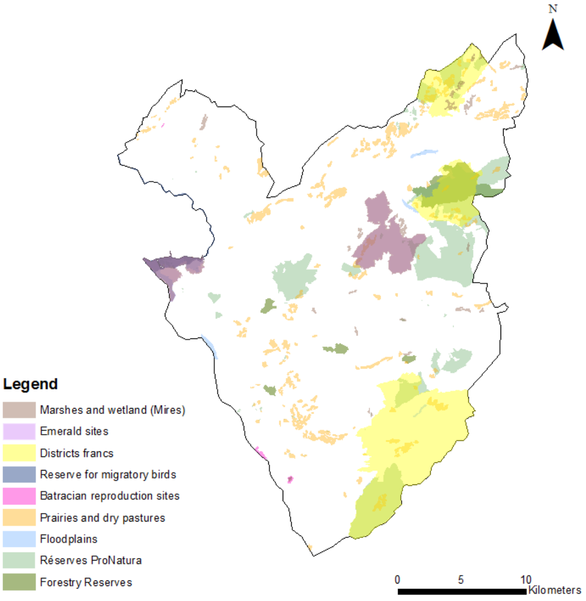

Figure 21: Protected areas under programs for biodiversity (Office Fédéral de Topographie Swisstopo, 2015)

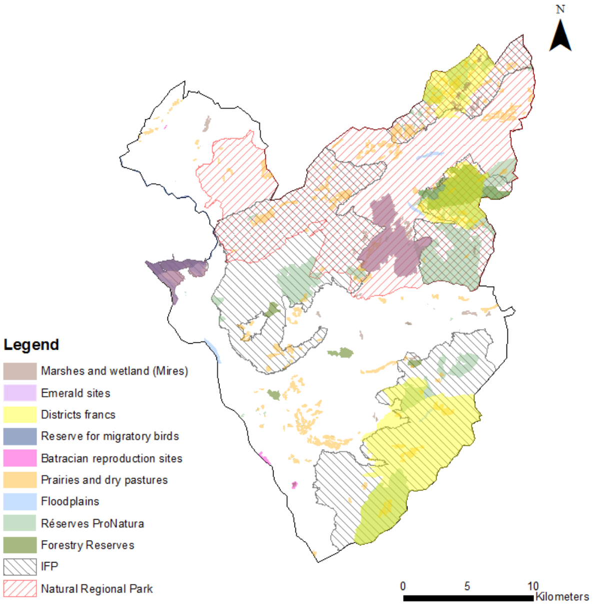

Figure 22: All protected areas (Office Fédéral de Topographie Swisstopo, 2015)

There are several possible ways to categorise the existing protected areas: direct or indirect protection of biodiversity, public or private initiatives and their importance measured using either the IUCN Protected Area Management Categories (IUCN & United Nations Environment Programme, 2014), or the degree of protection imposed by law.

For the purposes of this work, and keeping in mind all the ideas expressed above, we divided the protected areas in four tiers of biodiversity conservation priority (Figure 23).

The first tier is composed by the only type of protected area that is classified under IUCN as the top protected category Ia: the Federal Inventory of Raised and Transitional Mires of National Importance. In total, the first tier includes around 3% of the total area.

These are certainly the most protected biotopes by national law, with their protection starting in the constitution and making its way through subsequent levels of legislation. Human activities in these spaces are highly regulated but not prohibited. In fact, owing to the nature of these areas, they require active maintenance, and so conditioned traditional agriculture is incentivised (*Constitution Fédérale de la Confédération Suisse*, 1999) (*Loi Fédérale sur la Protection de la Nature et du Paysage*, 1966) (*Ordonnance du 21 Janvier 1991 sur la Protection des Hauts-Marais et des Marais de Transition d'Importance Nationale*, 1991)

(*Ordonnance du 7 Septembre 1994 sur la Protection des Bas-Marais d'Importance Nationale*, 1994) (*Ordonnance du 1er Mai 1996 sur la Protection des Sites Marécageux d'une Beauté Particulière et d'Importance Nationale*, 1996).

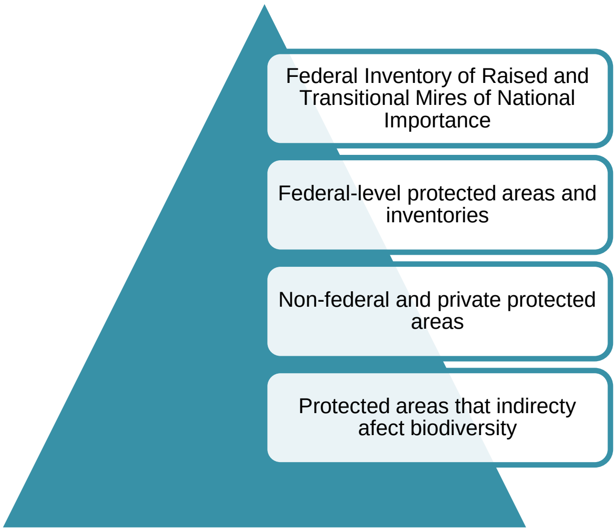

Figure 23: Protected area tiers

The second tier comprehends all federal inventories related to biotope protection and federal-level protected areas under IUCN classification IV. They present constraints to destructive human activities, pollution, and hunting:

- **Emerald Sites:** areas that are part of the European effort to preserve wildlife and its natural habitats, joined by Switzerland since the signing of the Bern Convention (*Convention du 19 Septembre 1979 Relative à la Conservation de la Vie Sauvage et du Milieu Naturel de l'Europe*, 1979)
- **Federal Hunting Reserves:** known as "districts francs", these are protected areas mainly concerned with the protection of mammals and birds (*Loi Fédérale du 20 Juin 1986 sur la Chasse et la Protection des Mammifères et Oiseaux Sauvages*, 1986) (*Ordonnance du 30 Septembre 1991 Concernant les Districts Francs Fédéraux*, 1991)
- **Federal Inventory of Alluvial Zones of National Importance:** areas concerned with the preservation of fauna and flora, maintenance of hydric systems, and geomorphologic particularities (*Ordonnance du 28 Octobre 1992 sur la Protection des Zones Alluviales d'Importance Nationale*, 1992)

- **Federal Inventory of Fenlands of National Importance:** areas dedicated to the preservation of prairie dynamics and biodiversity (*Ordonnance du 13 Janvier 2010 sur la Protection des Prairies et Pâturages Secs d'Importance Nationale*, 2010)
- **Federal Inventory of Reserves for Waterbirds and Migratory Birds of International and National Importance:** areas that result from the transposition of international conventions regarding the importance of wetlands as habitats of particular importance for birds, namely the Ramsar Convention (*Convention du 2 Février 1971 Relative aux Zones Humides d'Importance Internationale Particulièrement Comme Habitats des Oiseaux d'Eau*, 1971) (*Ordonnance du 21 Janvier 1991 sur les Réserves d'Oiseaux d'Eau et de Migrateurs d'Importance Internationale et Nationale*, 1991)
- **Federal Inventory of Amphibian Spawning Areas of National Importance:** protected areas with a focus on the protection of amphibians and their spawning sites (*Ordonnance du 15 Juin 2001 sur la Protection des Sites de Reproduction de Batraciens d'Importance Nationale*, 2001)

The third tier comprises two types of protected areas that have simultaneously great similarities and differences: Forestry reserves and Pro-Natura reserves. These two types of areas are protected for biodiversity conservation but neither is classified under IUCN categories.

Forestry reserves are mainly a public initiative on the cantonal level and lack the strength of federal-protected areas. They are created through contracts established with private parties, with duration ranging from 50 to 99 years, and their main goal is to allow the complete natural development of forest ecosystems.

Pro-Natura reserves also often focus on forest areas and are private initiatives developed by this Swiss civic group that lobbies environmental conservation. Pro-Natura acquires the land and manages it for conservation.

Finally, in the fourth tier we have other types of protected areas that indirectly affect conservation. They are not assigned IUCN categories and their focus is on traditional human activity and cultural landscapes. In our study area, they consist of the Federal Inventory of Landscapes and Natural Monuments of National Importance[6] and the Gruyère Regional Park.

An info-gap analysis was performed on the four tiers using Zonation and its analysis area mask option. The parameters in Table 8 were used to run an analysis on the set of protected areas that are part of each tier. The run info file generated listed the species from our binary datasets that were contained or missing from the protected areas.

Table 8: Info-gap analysis parameterisation

Removal rule	ABF
Warp factor	100 cells removed per iteration
Edge removal	Active
SSI	Active
Exponent of the species area curve (z)	0.25
Biodiversity/SSI features weight (w)	1
Biodiversity/SSI features quotient (x)	0.25
Removal mask	Active: urban area
Analysis area mask	Active: protected area

It shows that 89% of the species used in our biodiversity assessment had occurrences in the protected areas for biodiversity conservation, whereas only 66% of SSIs are represented (Figure 24). The total rises to 96% when including protected areas indirectly affecting biodiversity, encompassing 89% of the SSI. The remaining 11% of species classified as SSI are out of any protected area.

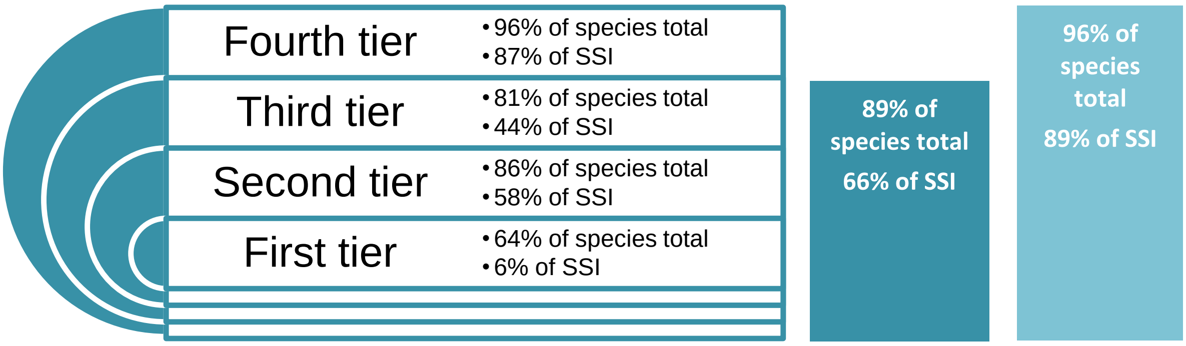

Figure 24: Info-gap analysis of the protected area tiers

5.2.4 National conservation goals

The Swiss Biodiversity Strategy (SBS) was designed in 2009 by the Federal Council and follows the motto: “Biodiversity is rich and capable of reacting to change. Biodiversity and its ecosystem services are conserved in the long term” (Wiedmer & Wisler, 2014). The overall

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[6] L'inventaire fédéral des paysages et des monuments naturels d’importance nationale (IFP)

goals of SBS are to safeguard species variability in its natural range and preserve functional ecosystems so that nature can follow its course by adapting to the changing conditions, guaranteeing the continual fulfilment of eco-services.

Following a highly participatory process, involving various stakeholders and adding to the international compromises pledged by Switzerland with the Nagoya Protocol and the Aichi Biodiversity Targets, ten goals were established (summarised in Table 9).

Table 9: Strategic goals of the Swiss Biodiversity Strategy (Wiedmer & Wisler, 2014)

Strategic goal	Targets
Use biodiversity sustainably	• By 2020, the use of natural resources and interventions involving them are sustainable, so that the conservation of ecosystems and their services, and of species and their genetic diversity, is ensured.
Develop ecological infrastructure	• By 2020, an ecological infrastructure consisting of protected and connected areas is developed. The state of threatened habitats is improved.
Improve the conservation status of national priority species	• By 2020, the conservation status of the populations of national priority species is improved, and their extinction prevented insofar as possible. The spread of invasive alien species with the potential to cause damage is contained.
Conserve and promote genetic diversity	• By 2020, genetic impoverishment is decelerated and, if possible, halted. The conservation and sustainable use of genetic resources, including that of livestock and crops, is ensured.
Evaluate financial incentives	• By 2020, the negative impacts of existing financial incentives on biodiversity are identified and avoided, if possible. Where appropriate, new positive incentives are created.
Record ecosystem services	• By 2020, ecosystem services are recorded quantitatively. This enables their consideration in the measurement of welfare as complementary indicators to gross domestic product and in regulatory impact assessments.
Generate and disseminate knowledge	• By 2020, sufficient knowledge about biodiversity is available to society and provides the basis for the universal understanding of biodiversity as a central pillar of life and for its consideration in relevant decision-making processes.
Promote biodiversity in settlement areas	• By 2020, biodiversity in settlement areas is promoted so that settlement areas contribute to the connection of habitats, settlement-specific species are conserved, and the population is able to experience nature in the residential environment and in local recreational areas.
Strengthen international commitment	• By 2020, Switzerland’s commitment to the conservation of global biodiversity at the international level is strengthened.
Monitor changes in biodiversity	• By 2020, the monitoring of changes in ecosystems, in species, and in genetic diversity is ensured.

The action plan towards the implementation of SBS, still in development, divides the action into five work areas: sustainable use of biodiversity, promotion of biodiversity, economic value, development and dissemination of knowledge, and international engagement. However, the growth in biodiversity considerations continues to be driven by sectoral policies, in an ongoing process of addition to thematic programmes that cover a diverse array of areas, such as culture, education, economic activities and spatial planning.

5.3 Socio-economics

5.3.1 Characterisation, land use, and land value

The study area is divided in two districts, Riviera-Pays-d'Enhaut and Aigle, which are in turn subdivided in 28 communes. Like most of Switzerland, the tertiary sector is the one with the greatest weight, followed by the secondary and primary sectors (Office Fédéral de la Statistique Suisse, 2015). Still, cultural identity is substantially rooted on a time when agriculture had more weight, and the landscape shows it.

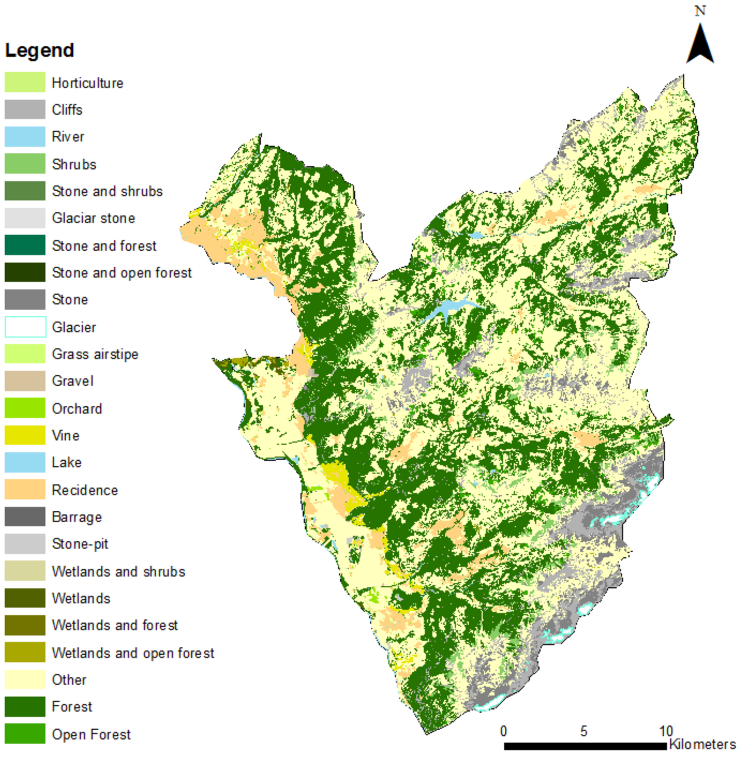


Figure 25: Land use based on VECTOR25 (Office Fédéral de Topographie Swisstopo, 2008)

The diverse topographic and bioclimatic conditions are responsible for a heterogeneous and interesting mix of land occupation, as shown in Figure 25.

Lowland areas around the Lake Leman are the most densely populated and are mostly occupied by urban areas and high-revenue agriculture, including vineyards, orchards, and irrigated cultures. That trend extends to the Rhone valley, which, although less densely populated, is attractive for both industries and high-revenue cultures due to its flatness, soil, and water accessibility.

Further from the lake and the flatlands, urban areas change their characteristics, becoming less dense and more disperse. In intermediate altitudes, the primary sector turns to forestry and animal raising.

There are several certifications that can be acquired by traditional agricultural products from the area, lending them extra value. An example is the protected designation of origin for the Etivaz cheese.

The higher elevations are strongly pursued for tourism and recreation activities, both by their suitability to winter sports and the proximity to nature.

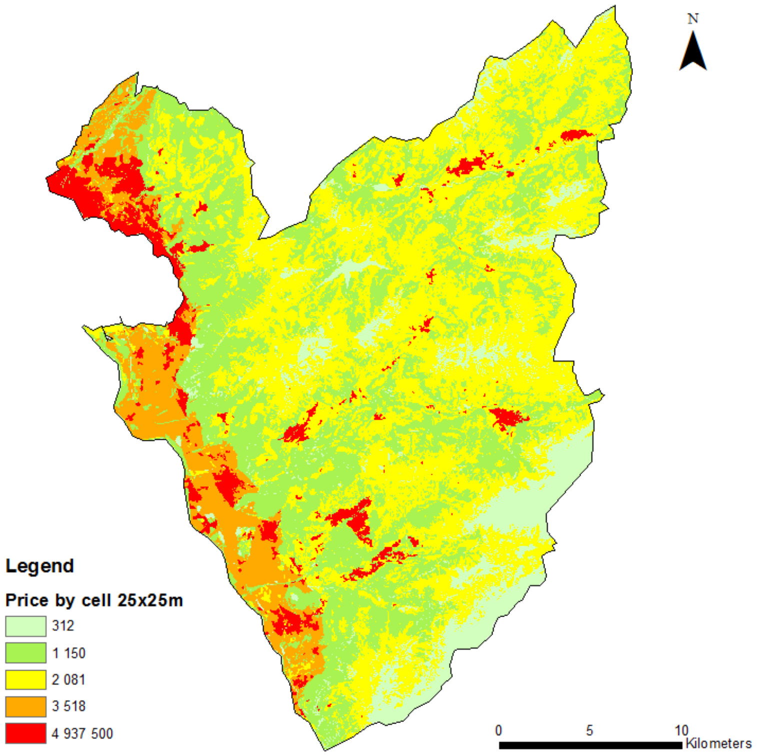


Figure 26: Estimated land acquisition cost in Swiss Francs per cell

These socio-economic matters generally reflect themselves in land acquisition prices. Unfortunately, we were unable to procure complete data about the average price of land acquisition by type of use for Vaud. The solution found was to cross-reference the incomplete data for Vaud with that of another Canton whose complete set was available, using the difference between known values from the same source as a proxy for the difference between values in other land-use categories (Fistat Fondation Interjurassienne pour la Statistique, 2014; Office Fédéral de Topographie Swisstopo, 2008; Prix-immobilier.ch, 2012). The resulting estimated acquisition costs are presented in Figure 26.

5.4 Biodiversity

5.4.1 Presence-absence data

Presence and presence-absence data are the basis for many studies in biology and conservation. Even without a comprehensive view of species distribution, they can provide relevant information, aiding to understand the ecological context of the study area better.

The extensive data in this format, produced at ECOSPAT in the University of Lausanne, posed the opportunity to investigate and relate this data with information pertaining to conservation and legal status.

In a first approach we related species of five different taxa — grasshoppers, butterflies, bumblebees, amphibians, and vegetation — to the Red Lists at the national, European, and international levels (European Commission, 2015; IUCN, 2015; Office Fédéral de l'Environnement OFEV, 2014). This effort ranged from inconclusive to informative. The first assessment indicated that, for all but the amphibians, information was not available in all three scales, or was tremendously incomplete (see Table 10). This made it impossible to analyse the conservation status across scales, except for the amphibians, for which the national scale had comparatively worse classifications in relation to the others.

Table 10: Summary of existing information/status/importance by taxa

	Grasshoppers	Butterflies	Bumblebees	Amphibians	Vegetation
International Red List	Extremely incomplete	Extremely incomplete	Extremely incomplete	Good	Extremely incomplete
European Red List	Non-existent	Good	Good	Good	Extremely incomplete
National Red List	Good	Good	Very outdated	Good	Good
Legal importance	Some	Some	None	High: all protected by law	Medium

The national scale presented some surprises, as was the case for the butterflies, which included seven endangered species, and the vegetation, with not only critically endangered but also regionally extinct species.

Using a similar strategy, we related species data to legislation, concluding that some taxa are more protected than others for no clear objective reason. This is most likely due to societal perception, as explained in Chapter 2.

Since habitat suitability maps were only available for vegetation, we decided to focus on this group and select the SSI inputs from the same pool. We selected all the species from the vegetation dataset that were classified as legally protected in our study area. These include both species that have a Red List Status of vulnerable or higher (Office Fédéral de l'Environnement OFEV, 2014) and those explicitly mentioned in legislative documents (*Ordonnance sur la Protection de la Nature et du Paysage (OPN)*, 1991) (*Règlement Concernant la Protection de la Flore*, 2005), resulting in a total of 140 species (list in Appendix 4) with the National Red List status distribution in Figure 27.

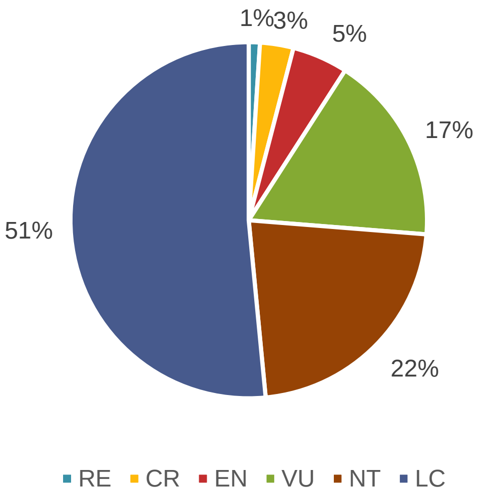


Figure 27: Conservation status of SSIs

5.4.2 Species distribution models and habitat suitability maps

As previously mentioned, high quality information regarding species distribution and habitat suitability is not always easy to obtain, in spite of being extremely important for decision making in conservation. In order to fill in the gaps, SDMs have become an important tool.

The habitat suitability maps available for this thesis pertain to vegetation. They are the result of work by members of the ECOSPAT Group at the University of Lausanne and gave rise to a previous publication which fully details the process that we summarise below (D'Amen et al., 2015).

Species were modelled using presence-absence data for the study area, acquired between 2002 and 2009, following a random-stratified sampling design limited to non-woody open vegetation and using modelling techniques in R 2.14.1 with the Biomod package (D'Amen et al., 2015; Dubuis et al., 2011).

Five variables and three modelling techniques were used — generalised linear models (GLMs), generalised additive models (GAMs), and generalised boosted models (GBMs) — and the resulting projections were averaged.

An additional thirty eight species were modelled using the same technique, raising to 279 the number of species with available high quality suitability maps at a scale of 25x25 m (list in Appendix 3).

Owing to computational reasons, and in order to facilitate comparisons, we make use of the probabilistic modelled output forms. In earlier experiments, we saw that binary maps performed poorly with the CAZ cell remover in Zonation.

Following the same comparative strategy we used for species with presence-absence data, we compared the modelled species to the national Red List and legal status. Due to the high number of occurrences needed to produce quality models, it is not surprising that we have no models for species in the extinction risk categories. Still, there is a small number of species, approximately 6%, that are protected by law (*Ordonnance sur la Protection de la Nature et du Paysage (OPN)*, 1991) (*Règlement Concernant la Protection de la Flore*, 2005).

6 Results and Discussion

6.1 Rarity versus richness and species weighting using biodiversity

Biodiversity conservation strategies rarely attain an equilibrium between protecting rarity and protecting richness. Realistically, in a world of limited resources, one must usually privilege one of the strategies knowing that they will yield different results.

The same can be said about assigning weights to species. On the one hand, one could make an ethical argument that all species have the same right to live. On the other hand, the disappearance of some species will be more costly to the ecosystem or to mankind, and it is therefore natural that an emphasis is placed on their protection.

We tried to ascertain the impact of these two variables on vegetation conservation prioritisation using only biodiversity features. Working with Zonation and biodiversity features comprising habitat suitability probability maps for 279 species and presence-absence data for 140 SSIs, we compared the results of prioritisation using CAZ function and ABF for four different weighting strategies.

The entire work uses a warp value of 100 (number of cells removed per iteration) and an ABF exponent of 0.25 (theoretical value of the exponent of species–area curve) with the intent to minimise the extinction risk prediction across features.

In this chapter, we primarily present maps that are generated in Zonation, using the default colour scheme, where the biological value of the site is represented by:

- red — the best 2% of the landscape
- dark red — the best 2-5%
- magenta — the best 5-10%
- yellow — the best 10-25%
- light blue — the best 25-50%
- dark blue — the best 50-80%
- black — the best 80-100% (or the least-valuable 20%)

In the first weighting strategy, we used what could be called the ethical or control approach, assigning the same weight (1) to all species. We ran Zonation using both CAZ and ABF, producing the priority distribution maps shown in Figure 28 and Figure 29.

For the second weighting strategy, we set the weight of each species based on the national Red List classification (Office Fédéral de l'Environnement OFEV, 2014). Species not evaluated or with deficient data were given the same weight as the lowest Red List category assessed (Figure 30 and Figure 31).

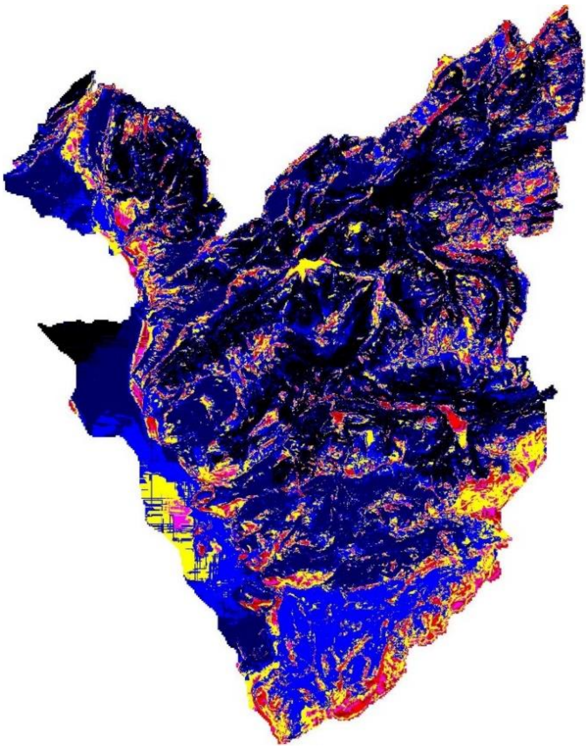
The third weighting strategy was based on the legal status of species, where weight 1 was given to all non-protected species and weight 3 to all species belonging to a protected category (extinction risk in national Red List categorisation and/or mention in legal documents) (Figure 32 and Figure 33).

The fourth weighting strategy used information from both the national Red List classification and the species legal status. A 2-point bonus was given to national Red List values for species under legal protection (Figure 34 and Figure 35).

The results reveal significant differences between the top areas identified for conservation using CAZ or ABF, confirming that a tendency towards rarity or richness substantially affects the spatial translation of conservation strategies. The two algorithms seem to be much more consensual where the selection of areas of lower importance is concerned.

Results with ABF produce a more aggregate solution, which is generally seen as positive for conservation, allowing for more species mobility, but both solutions retained the representativeness of all SSIs, even when only considering the best 3% of the area. The third and fourth strategies fare even better and retain all species down to the top 1% of area, using both CAZ and ABF (Appendix 5: plots 1-8).

Regarding the weighting, at this very detailed scale — unusual for traditional conservation projects — we observe an unexpected spatial consistence, with minute differences that could be worked into a conservation plan, if deemed relevant, in line with the Swiss legislative context and the existing practice of conserving small areas.



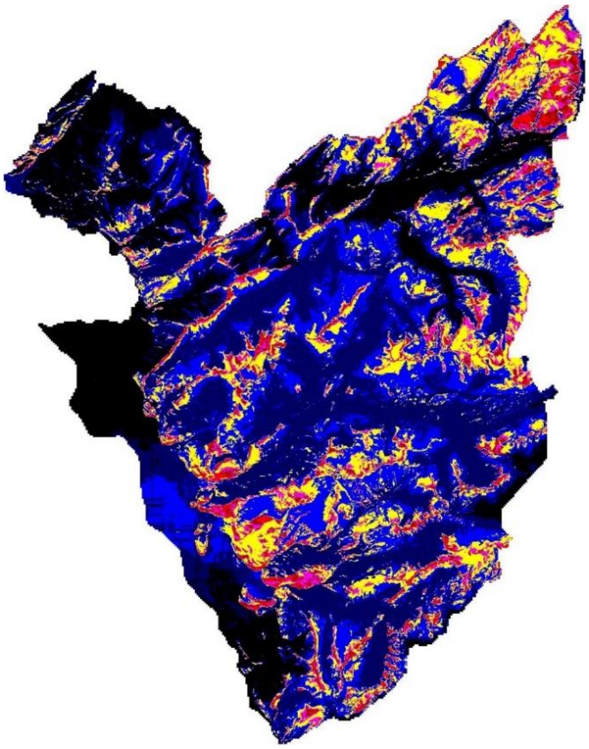
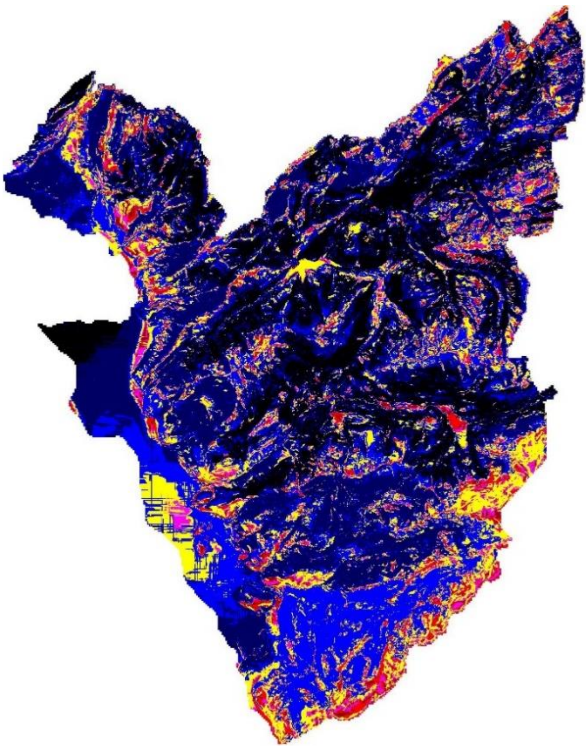


Figure 28: CAZ with biodiversity features and ethical weighting where weight=1 for all species (scenario AA1)

Figure 29: ABF with biodiversity features and ethical weighting where weight=1 for all species (scenario AA2)



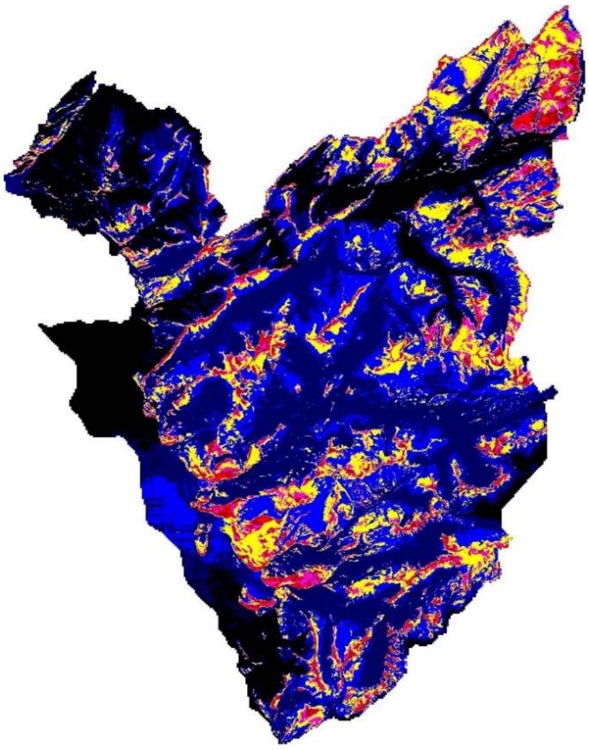


Figure 30: CAZ with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5, and RE=6 (scenario AB1)

Figure 31: ABF with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5, and RE=6 (scenario AB2)

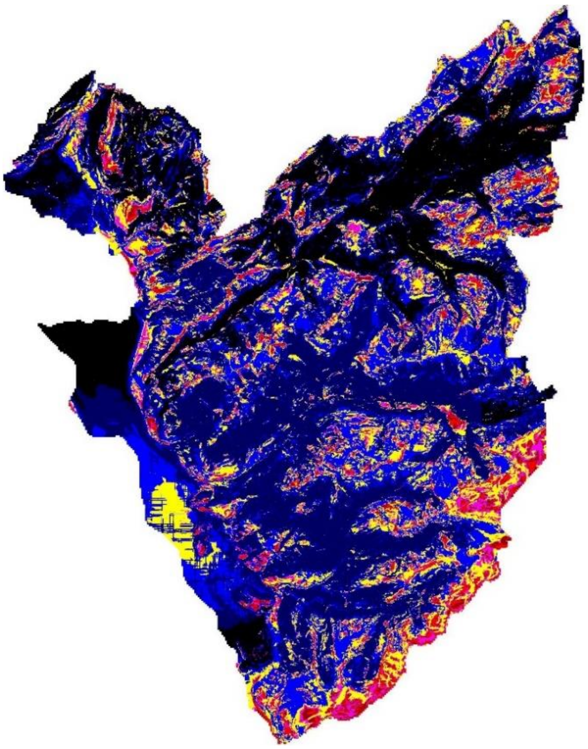


Figure 32: CAZ with biodiversity features and legal status weighting where protected=3, not protected=1 (scenario AC1)

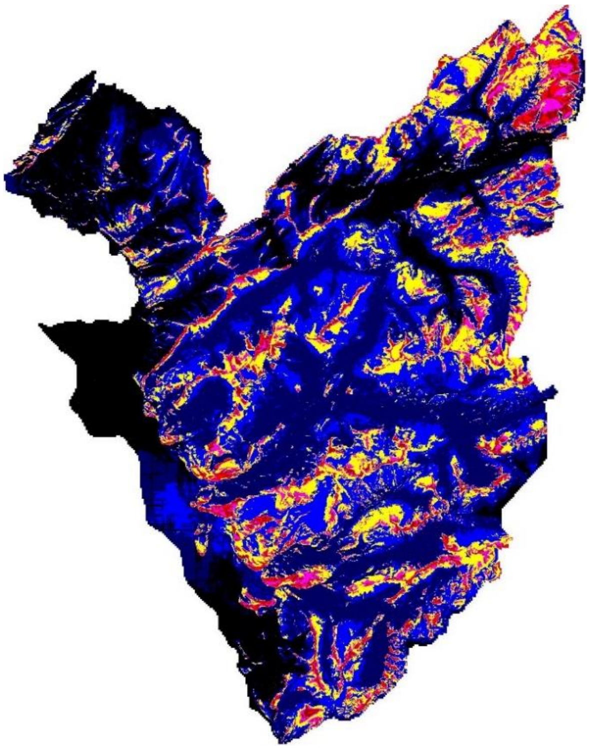


Figure 33: ABF with biodiversity features and legal status weighting where protected=3, not protected=1 (scenario AC2)

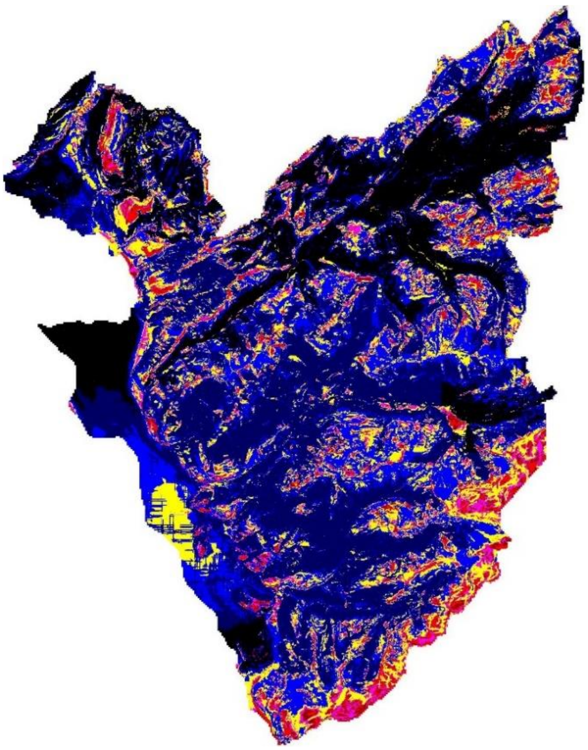


Figure 34: CAZ with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD1)

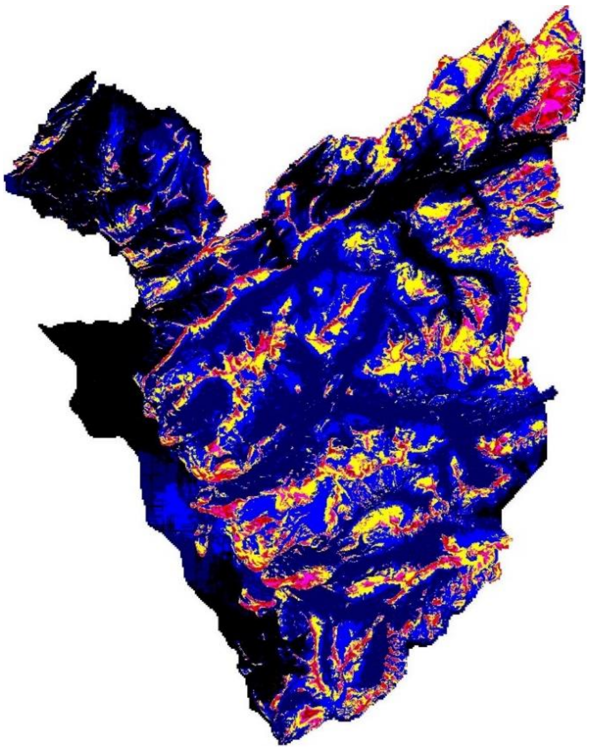


Figure 35: ABF with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD2)

Weighted extinction risk seems to take a similar behaviour in all scenarios, with a sharp rise in risk after 90% of the landscape is lost, reaching 0.7 when only the top 3% are left (Appendix 6: plots 1-8).

The costs, which in this case can only be measured by the size of the protected area, are the inverse of the proportion of landscape removed. Both analyses show an expected trend in which CAZ fares better, especially without species weighting, as it tries to protect the core areas for all species equally (Appendix 7 and 8: plots 1-8).

We selected six random species to observe the evolution of their remaining distribution at proportions of landscape lost ranging from 80% to 95%. The species selected were (1) *Ajuga reptans*, (2) *Athamanta cretensis*, (3) *Cirsium acaule*, (4) *Drias octopetala*, (5) *Gentiana* acaulis, and (6) *Helictotrichon pubescens.* The differences between CAZ and ABF are evident, although somewhat fading as the area is decreased. Some species fare better with the use of CAZ (Species 2) and others with the use of ABF (Species 4).

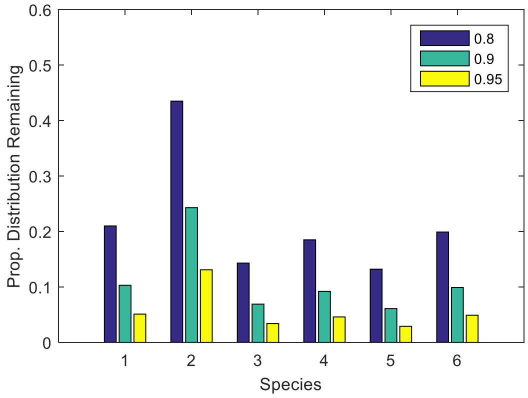


Figure 36: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in CAZ with biodiversity features and ethical weighting where weight=1 for all species (scenario AA1)

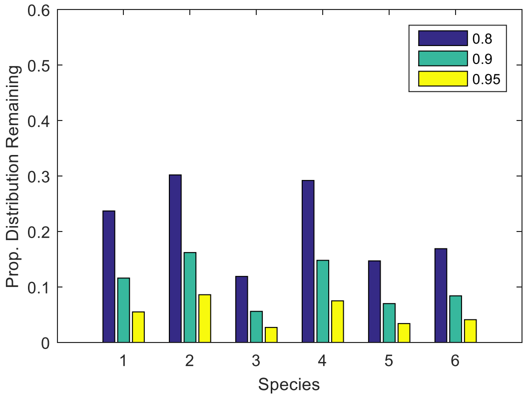


Figure 37: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in ABF with biodiversity features and ethical weighting where weight=1 for all species (scenario AA2)

Based on our examination, we believe that the fourth weighting strategy is the most practical scenario in real-world conservation planning. Combining the top 25% areas resulting from the CAZ and ABF analysis (this number was chosen as it is close to the total percentage of protected area under programs for biodiversity in vector format even though conversion to raster introduces a small discretisation error, placing that number at roughly 23%), we conclude that their intersection accounts for approximately 12% of the territory, and the union of the areas selected by each one would cover around 37%. South-facing slopes seem to be significantly represented in the convergence of the best sites (Figure 38).

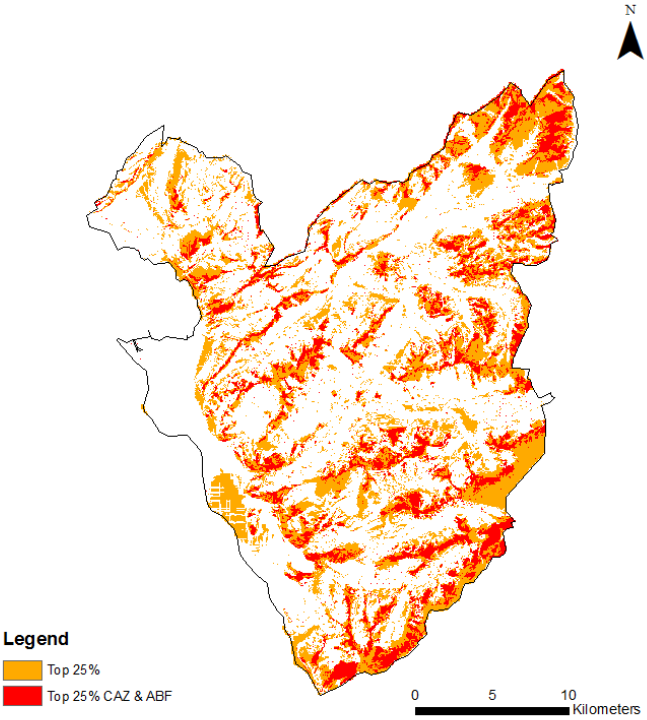


Figure 38: Combination of the 25% best-ranked landscape using CAZ and ABF and the 4th weighting strategy (scenarios AD1 and AD2)

6.2 Socio-economic data in the prioritisation process

Biodiversity does not exist in isolation from anthropic systems, and to protect it we must account for both economic and social constrains that may affect the implementation of a successful conservation plan. In this section we considered the following premises:

- In urban areas, the likelihood of a species suitability niche being realised is low, and so is the likelihood of urban areas being turned into conservation areas in the near future: that would imply either a major social shift or a catastrophic event. Accordingly, those should be the first areas to exclude from the prioritisation analysis.
- Land use and land acquisition are historically of major importance to the creation of conservation areas, both stemming from public or private initiative, and have to be taken into account in a more realistic approach to conservation.
- Political will for conservation is intrinsically connected with social acceptance of measures limiting human impact in the landscape and, to a degree, it also affects the feasibility of a project.

- A realistic species-weighting scheme for real life scenarios must include both extinction risks and legal considerations.

The inclusion of socio-economic data brought to light boundary errors in the study area, introduced in the rasterisation step. To avoid their impact in the prioritisation, we added a mask limiting the study area and excluding these error cells.

In the first analysis including socio-economic data, we excluded urban areas by using a mask that forced them to be removed first. We once again computed both CAZ and ABF analyses (Figure 39 and Figure 40).

In the second analysis, we included the estimated acquisition costs. We kept the removal mask for the urban areas, since acquisition costs do not account for the cost of rehabilitation and the result would be less credible (Figure 41 and Figure 42).

In the third analysis, we considered the previously calculated opposition to measures limiting human activity in the territory, which denoted political cost (Figure 43 and Figure 44).

Finally, the two costs were combined through multiplication (Figure 45 and Figure 46).

The results show that the integration of socio-economic data has a major impact on the selection, leading to substantially different top-ranked areas. It also impacts the difference between the two algorithms, which tend towards more coincident approaches (Figure 53).

Species features, especially SSIs, suffer slightly with excluding urban areas, even forcing the elimination of one species (*Lycopodium clavatum*) from the analysis. But the acquisition cost seems to be the main factor driving the need for larger areas to protect SSI biodiversity, forcing the replacement of high-value areas with larger plots of less valuable territory.

Acquisition cost, both on its own and in combination with political cost, further increases the area needed for complete SSI representation, now requiring the top 2% territory in CAZ scenarios and the top 8% in ABF (Appendix 5: plots 9-16).

The negative impact of the acquisition cost is not limited to SSIs. The proportion of species distribution remaining throughout the process also shows an early decrease, subtle in the CAZ analysis and sharp in the ABF analysis, which indicates that there is a greater biological value attributed to the (costly) cells excluded at the beginning of the process (Appendix 7: plots 9-16).

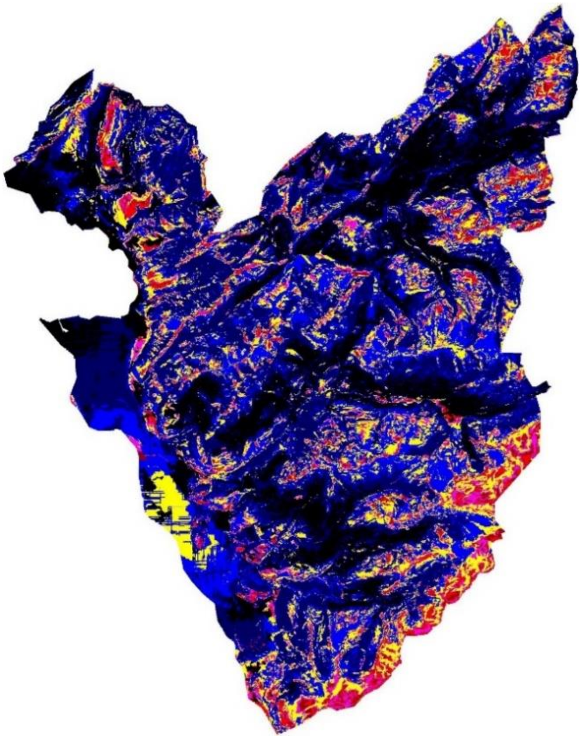


Figure 39: CAZ with the 4th weighting strategy and a mask to exclude urban areas (scenario BA1)

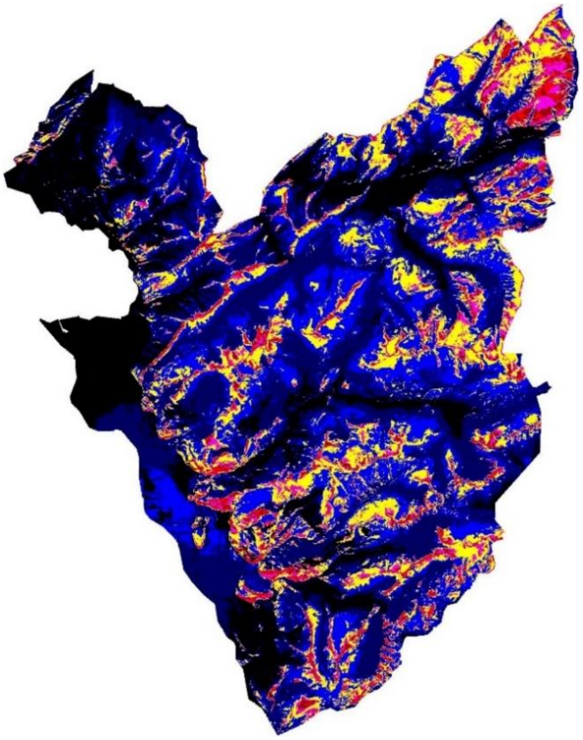


Figure 40: ABF with the 4th weighting strategy and a mask to exclude urban areas (scenario BA2)

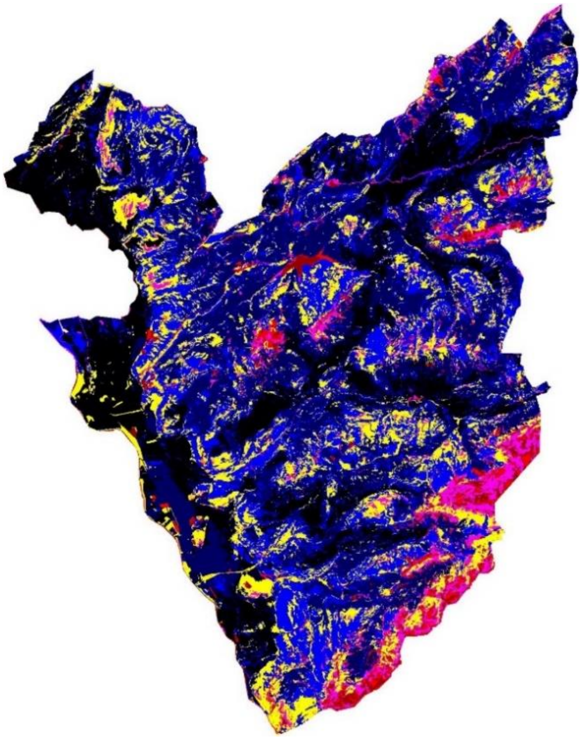


Figure 41: CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB1)

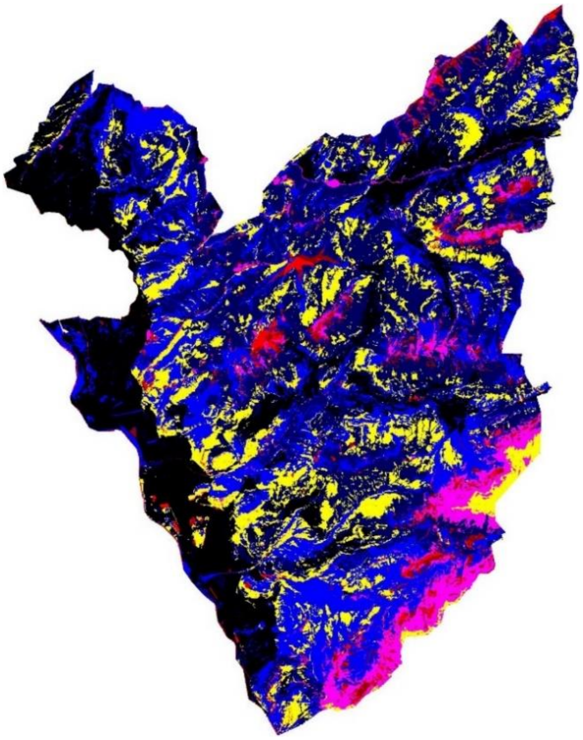
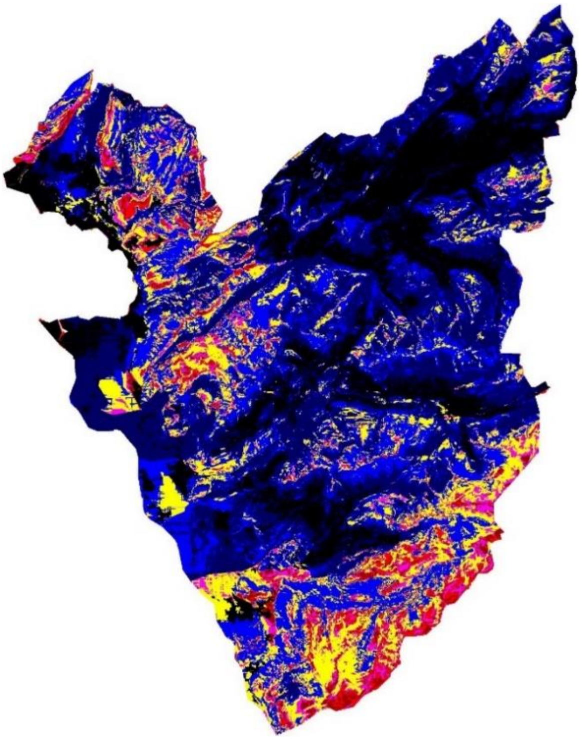


Figure 42: ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB2)



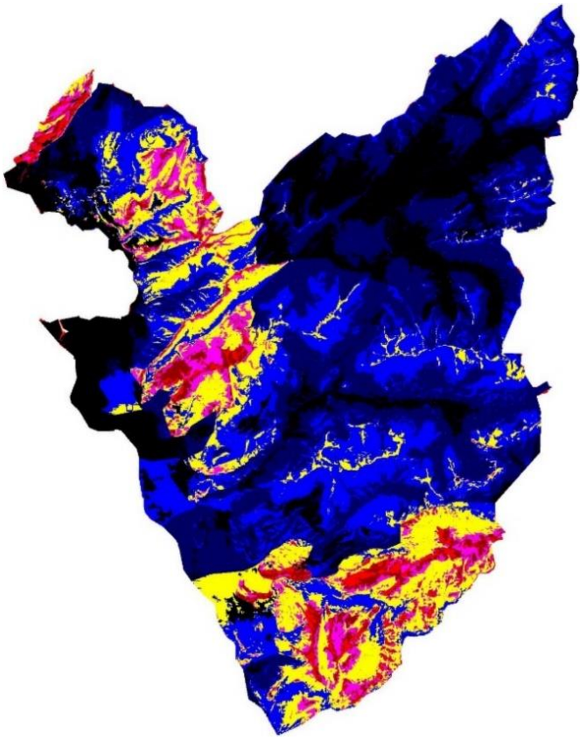
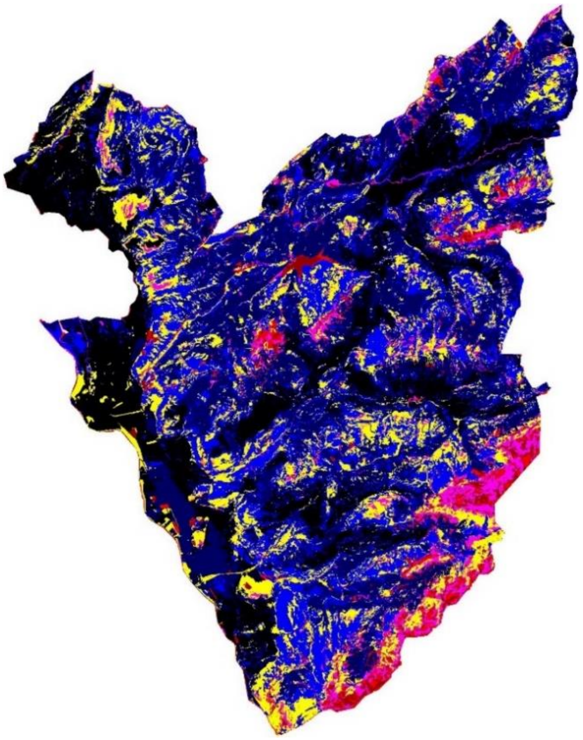


Figure 43: CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC1)

Figure 44: ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC2)



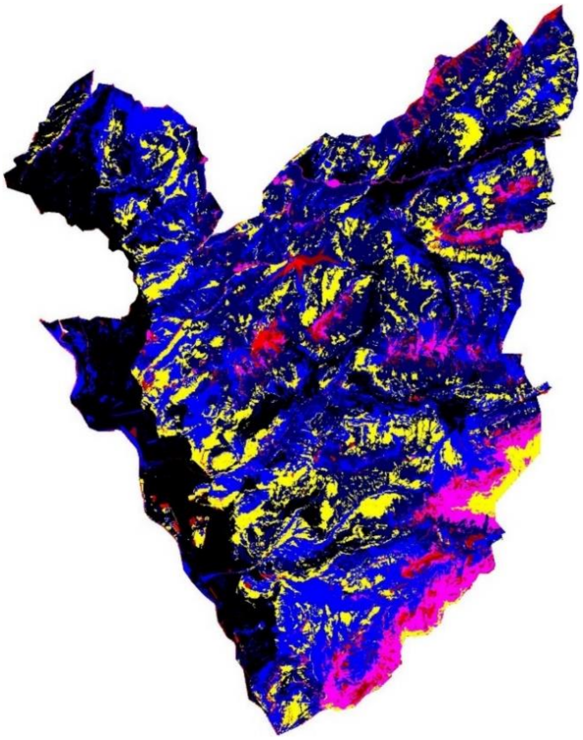


Figure 45: CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD1)

Figure 46: ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD2)

The distribution behaviour of the six previously studied species shows a significant loss whenever acquisition costs are considered, primarily for lower values of territory reserved, but benefits are seen for some species, namely for Species 2, who in larger top-ranked areas not only seems to fare better but to find an equally good solution in CAZ and ABF (Figure 47, Figure 48, Figure 49, and Figure 50).

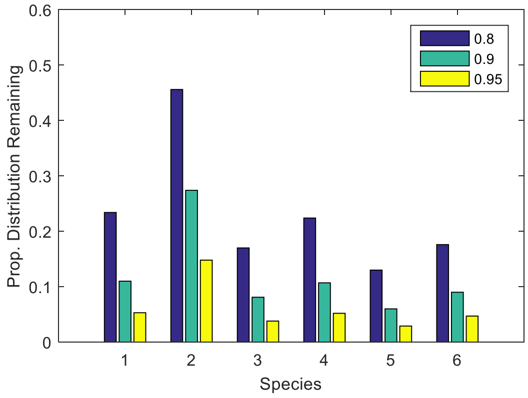


Figure 47: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in CAZ with the 4th weighting strategy and a mask to exclude urban areas (scenario BA1)

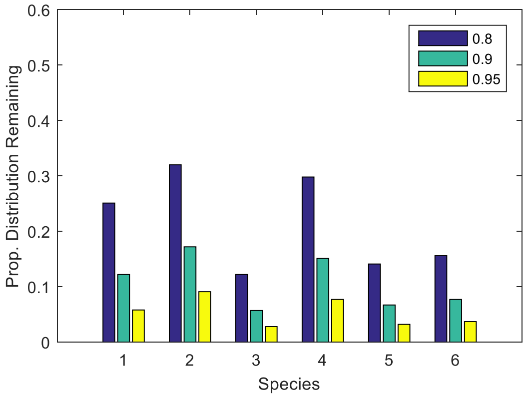


Figure 48: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in ABF with the 4th weighting strategy and a mask to exclude urban areas (scenario BA2)

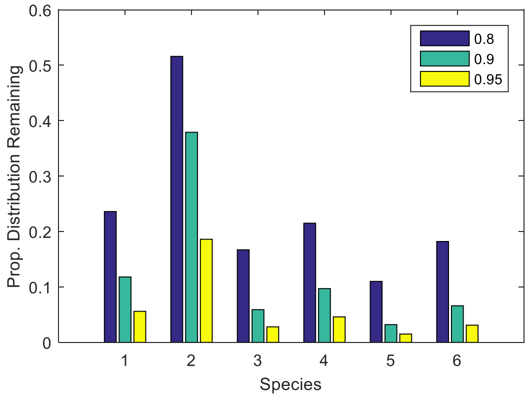


Figure 49: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD1)

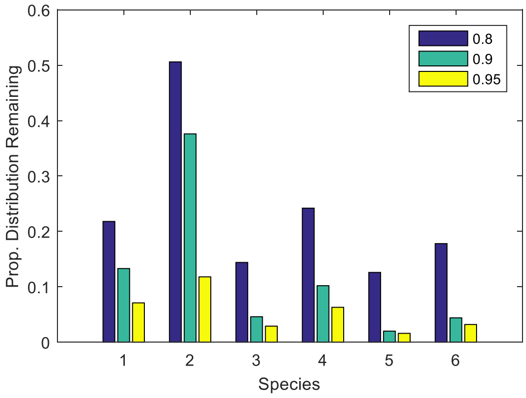


Figure 50: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD2)

The CAZ analysis including acquisition costs seems capable of maintaining species representation until later in the cell removal process, ultimately requiring a smaller conservation area and entailing lower acquisition costs. It is also able to maintain slightly better proportions of distribution, which is important for variability and conservation in the long run (Appendix 7: plots 9-16).

The increase in the minimum remaining distribution relative to the overall cost hits a plateau near 80%, after which improvements in results imply an exorbitant increase in extra cost for both CAZ and ABF. The ABF analysis shows a comparatively bigger lag to cross the first 30% of the minimum remaining distribution (Appendix 9: plots 1-4).

Despite yielding a substantial difference in the spatial area selected in comparison with the other maps, when assessing political cost independently, it was possible to conserve the full extent of biodiversity in the top 1-2% of the landscape (Appendix 5: plots 3-4).

Looking once again at the distribution of the six species considering political costs only, it is possible to see that the proportions are considerably different from the previous analyses, especially in the case of ABF, in which a more uniform distribution is perceived (Figure 51 and Figure 52).

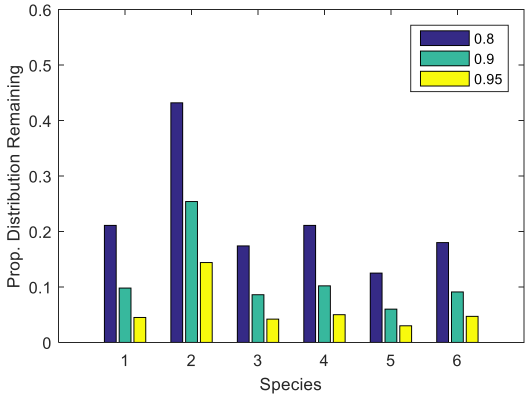


Figure 51: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC1)

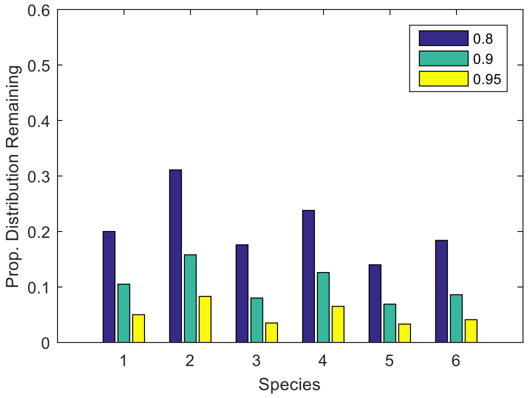


Figure 52: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC2)

The political cost, however, did not have a substantial impact in the last analysis despite being a multiplier on the acquisition costs (Figure 45 and Figure 46). That is not surprising, as the acquisition prices depend on land-use differences, which are much more abrupt than the ones in the political cost feature.

Although political costs might be important within the public decision sphere for limiting human activity, they appear less relevant when it comes to land acquisition or private actions, which means that their relative importance would need to be adjusted depending on the way that the conservation measures are intended to be applied.

The weighted extinction risk is stable, with strong similarities not only between the results generated in this analysis, but also with those from Section 6.1 (Appendix 6: plots 1-18).

In the combined analysis that accounts for both acquisition and political costs (the most likely scenario in this section), the overlap of the top 25% areas obtained using CAZ and ABF covers approximately 18% of the territory, climbing to 31% if we account for the union (Figure 53).

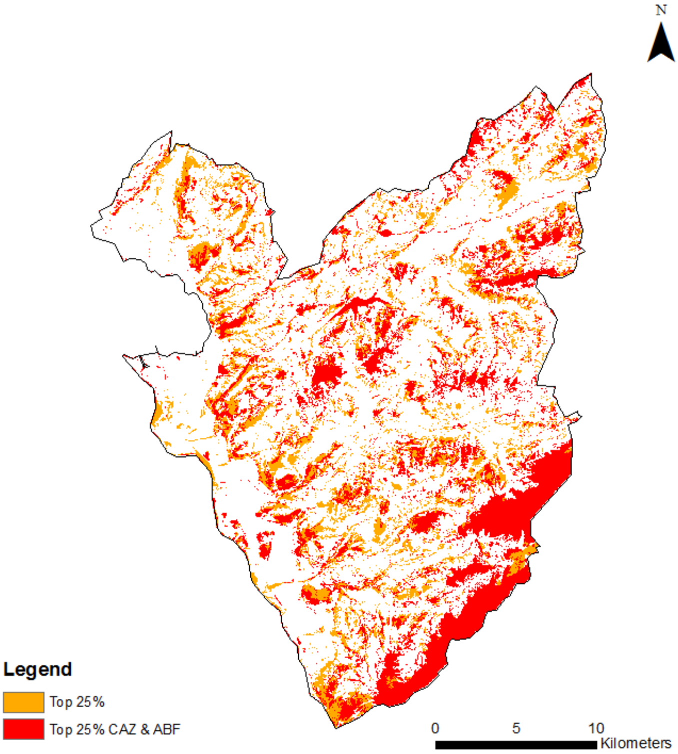


Figure 53: Combination of the 25% best-ranked landscape using CAZ and ABF and the 4th weighting strategy, with a mask to exclude urban areas and accounting for both acquisition and political costs (scenarios BD1 and BD2)

6.3 Comparing and expanding protected areas

Conservation areas are the cornerstone of most conservation planning strategies, and they are many and diverse in our study area. When comparing our results to the existing protected area coverage, it is important to have in mind that our prioritisation considered only vegetation, whereas these areas were defined by taking into account a broader set of species.

Even though vegetation is often used as a proxy for general biodiversity, it is not a perfect indicator, and a perfect overlap was never expected.

That being said, overlaps do occur when considering only biodiversity features, but there does not seem to be a definitive tendency towards richness or rarity in the existing areas. The overlap is more significant with the analysis that includes socio-economic costs, when the difference between CAZ and ABF results is also minimised (Figure 54 and Figure 55).

This is actually in line with the ad hoc history of conservation planning, where reserve areas were often chosen on an opportunistic basis, aiming for lands with low interest for other uses. The biggest matches seem to take place with *district franc* protected areas and private Pro-Natura reserves: the first may be explained by the relation between vegetation and the herbivore mammals that these areas were designed to protect.

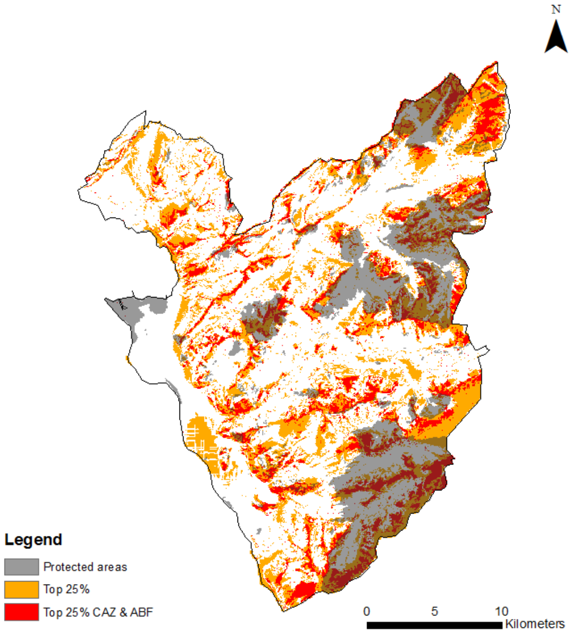


Figure 54: Overlap of direct protected areas with the combination of the 25% best-ranked landscape using CAZ and ABF and the 4th weighting strategy (scenarios AD1 and AD2)

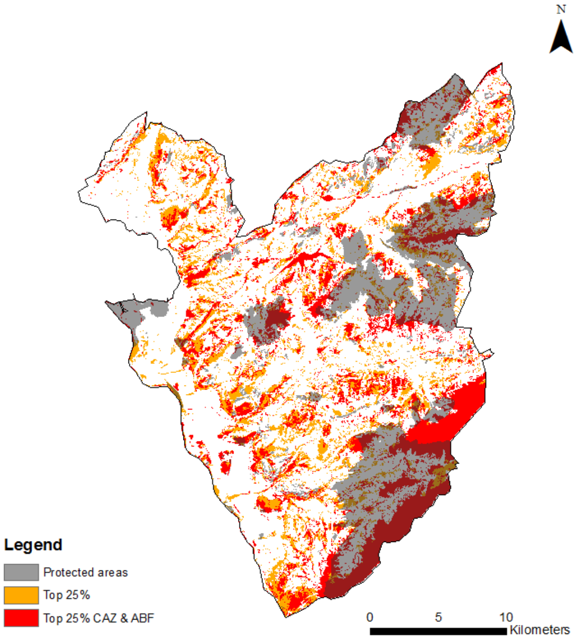


Figure 55: Overlap of direct protected areas with the combination of the 25% best-ranked landscape using CAZ and ABF and the 4th weighting strategy, with a mask to exclude urban areas and accounting for both acquisition and political costs (scenarios BD1 and BD2)

Still, there are several consensual top priority areas that would result in significant gains for vegetation protection. The most notorious is located at the eastern frontier of the study area and is already surrounded by two protected areas, showing potential for linkage.

To determine which areas have the greatest potential to increase protection, we again used the removal mask, this time not only marking urban areas as the first to be removed but blocking directly protected areas according to their strength. We then ran the analysis accounting for costs. Indirectly protected areas were not considered.

At first glance, the maps generated allowed us to identify top-importance areas inside the already protected areas. This approach might be crucial because it allows us to identify areas that could be bumped up in protection level in order to protect these particular species without going the more disruptive route of further constraining new areas and with it human activities (Figure 56 and Figure 57).

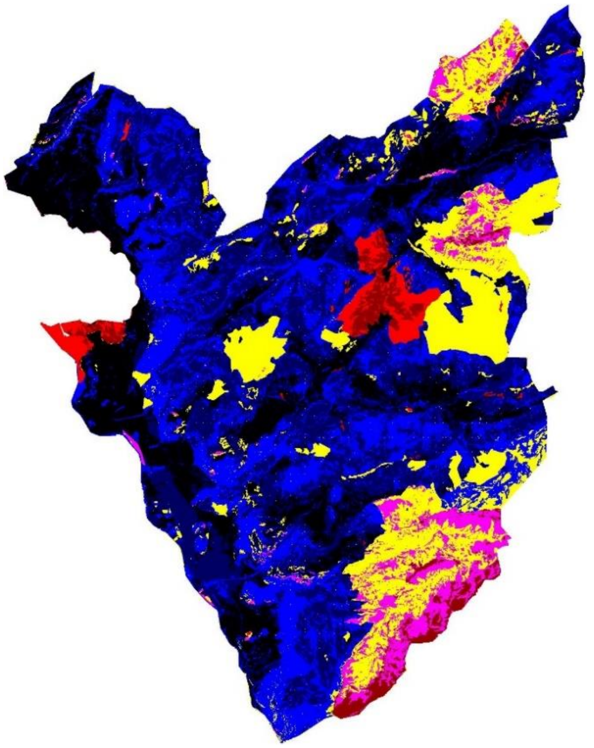


Figure 56: CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C1)

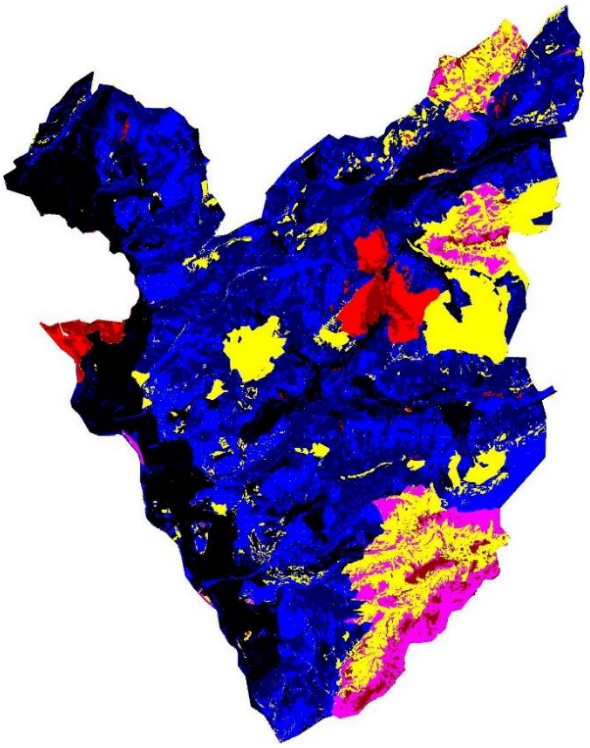


Figure 57: ABF with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C2)

Looking at the six randomly selected species and their proportion, there appears to be a convergence between CAZ and ABF results, and some species, notably Species 5, made significant preservation gains (versus Figure 49 and Figure 50) with the blocking of protected areas, whereas Species 2 and Species 6 suffered slightly with the change. Nevertheless, Species 2 seems to fare better in CAZ than in ABF when only the best 5% of the landscape is left (Figure 58 and Figure 59).

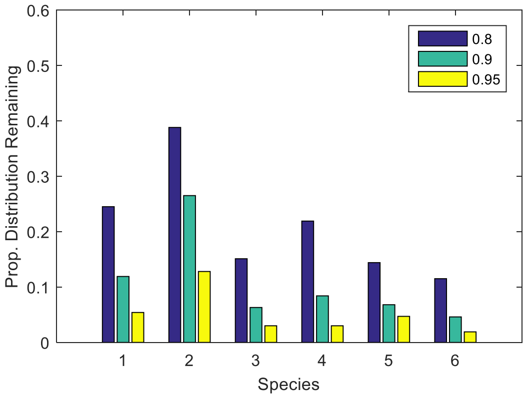


Figure 58: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C1)

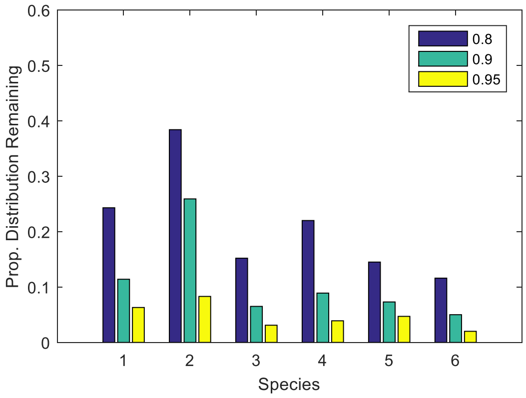


Figure 59: Proportion of distribution remaining for the six randomly chosen species at 80%, 90%, and 95% landscape lost in CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C2)

Analysing more deeply the data outputs, we conclude that, to protect the full representation of the SSIs, an increase of the protected area of roughly 2% would be necessary. Extending the protected area by that percentage, we get the results for potential expansion in Figure 60 and Figure 61.

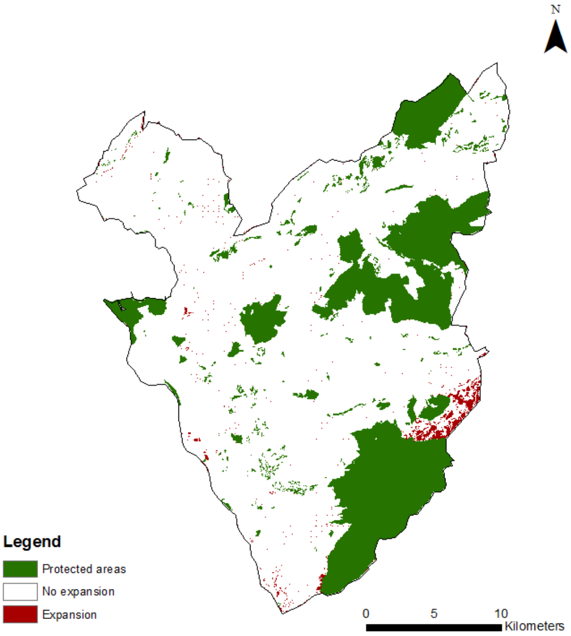


Figure 60: CAZ proposal of expansion by 2%

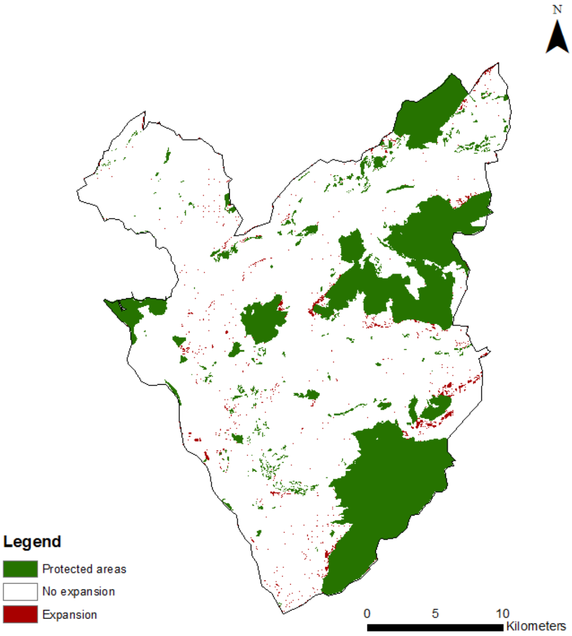


Figure 61: ABF proposal of expansion by 2%

In this assessment, both hypotheses safeguard the SSIs, but CAZ is significantly more agglomerated, which makes it more feasible for implementation and management than the ABF solution. The analyses also show some preference for an area to the east, located between two already protected areas, mentioned before as being a consensual location with potential for expansion of protected areas.

Previous trends of weighted extinction risk are maintained (Appendix 6: plots 17-18), and so are the effects of the costs mentioned in Section 6.2 over the proportion of distribution remaining, conserving the same pros and cons of each solution (Appendix 7: plots 17-18, Appendix 8: plots 17-18, Appendix 9: plots 5-6).

In this situation, like in most real cases, the results for the ultimate goal and target are similar, but the spatial distribution differs. The reasons that can shift decision makers towards one of the decisions are manifold, and there might not be a universally preferable one.

6.4 Zonation v4 perspectives

Zonation was created and developed to aid the conservation decision-making process, and to help identify, visualise, and ponder the different trade-offs between possible results. During the course of this research, we identified several advantages and disadvantages of its use.

Starting with the advantages, Zonation is clearly a flexible tool, capable of identifying the top areas for the maximum cover problem under different prioritisation needs and assumptions. It allows extensive possibilities of analysis, only a part of which were explored in this work.

The direct creation of visualisation maps and supporting information make it attractive when compared with other conservation prioritising software that often requires an external visualisation application.

The tool is not limited to conservation planning. It could be used in a diversity of decision problems with spatial transcription, depending on the input data, which would make it an excellent tool in spatial planning whenever some kind of zonation is involved.

On the negative side, we can say that, although a project creator is included with the latest version, many of the features of the program are not yet available. Manual preparation of command lines and settings is a tedious and time-intensive process that reduces the usability of the program.

As with other open-source projects, user support is practically non-existent. The official support forum was deactivated at the beginning of the year (2015), and even the new version of the manual does not account for changes between versions nor does it correct obvious errors from the previous version.

Solutions depend on a number of parameters that, though adjustable, are generally set making use of ill explained conventions or through sensitivity analysis, with no clear justification. It would be relevant to study the underlying processes further, yielding proper methodologies for parameter setting.

Finally, we believe that the advantages of using Zonation outweigh the disadvantages. In particular, the set-up for basic analyses is significantly more user-friendly than the average conservation planning support software and requires little-to-no knowledge of programming languages. From a real-world perspective, this alone makes it a particularly useful tool for decision making in a spatial context, especially outside academia.

7 Conclusion

In a world of finite resources, conservation planning is becoming increasingly important. This new approach, more systematic and scientifically supported, helps identifying priority areas of high value and allocating efforts and resources to where they can have a more positive impact to achieve conservation goals.

The information and new tools being developed through and for conservation planning have great potential use in spatial planning and could aid the development of more sustainable plans, promoting human occupation in areas of lower biological value and discouraging it in more valuable ones.

However, intervening in the territory is always a complex process, one that has to account for environmental and socio-economic specificities and that requires solid interdisciplinary knowledge and expertise.

The flexibility objective incorporated into the planning process to better adapt to different and changing conditions can also result in ambiguities and suboptimal choices. These ambiguities and the processes that create them need to be more fully understood in order to assess their spatial repercussions and impact on biodiversity and humans.

The study area chosen in the Alpine region of the Canton of Vaud was a perfect testing ground to analyse some of these ambiguities due to its prodigious biodiversity and to the amount of information available.

Focusing on vegetation biodiversity and using Zonation to analyse the similarities and dissimilarities of different conservation thought processes, preferences, and socio-economic data, we concluded that:

- Benefiting rarity or richness yield different spatial results in the selection of the best areas for conservation, with the benefits of selecting one over the other depending on territorial context.
- Weighting at this fine scale — where species of higher weight are SSIs — results in just subtle differences for conservation selection.

- Acquisition costs, unlike political costs in this scenario, do have a major impact in the selection of high-quality areas for conservation, tending to reduce the gap between CAZ and ABF scenarios.
- Current protected areas seem to be the product of a traditional opportunistic implementation although they already cover areas substantially important for the protection of vegetation biodiversity. An increase of just 2% of highest valued landscape would be able to retain almost full representation of the vegetation used in this study.
- There are a number of areas which constantly appear at the top of the quality ranking, being good candidates for future protection with vegetation biodiversity in mind.

This work demonstrates that there are no perfect solutions in conservation planning, only better or worse solutions whose value often depends on the context. Different thought processes generate different area rankings and spatial translations, but do not always yield major dissimilarities in terms of overall solution quality.

There are other processes and features that were not included in this work but whose importance for prioritisation recommends their incorporation into the conservation process. Among the most relevant, we count:

- the inclusion of more habitat suitability maps for rare and protected species, which are improving in quality with the development of species distribution modelling techniques
- the inclusion of negatively pondered alien invasive species, which can help avoid threatened sites or identify priority areas where prevention should be prioritised
- the inclusion of species-specific and general aggregation and connectivity specificities, features seen as important to the management of protected areas and the ability of species to circulate in the landscape and adapt to change
- the elaboration of analyses for different taxa, both individually and jointly, making it possible to assess divergences in priority areas and generate new potential scenarios and priority weights

- the inclusion of climate change scenarios, accounting for possible future niches and refuges for long term conservation
- the inclusion of economic benefits of conservation, such as ecological services
- the inclusion of weighting at different scales, allowing for better assessment of the importance of sites in a complete spatial context
- the inclusion of more diverse costs, conflicts, and threats that can affect conservation planning feasibility and real- life implementation

There is extensive space for the study of different input options and their effect on the prioritisation of conservation areas and the biodiversity features that they favour. As new information and data are deemed relevant and important to be included in the prioritisation for conservation processes, spatial data and information acquired through modelling become even more essential for high-quality and well-supported conservation planning.

Decision support software such as Zonation can play an important role in these studies, helping to quickly visualise the trade-offs of different scenarios and to find the most applicable choices for concrete cases.

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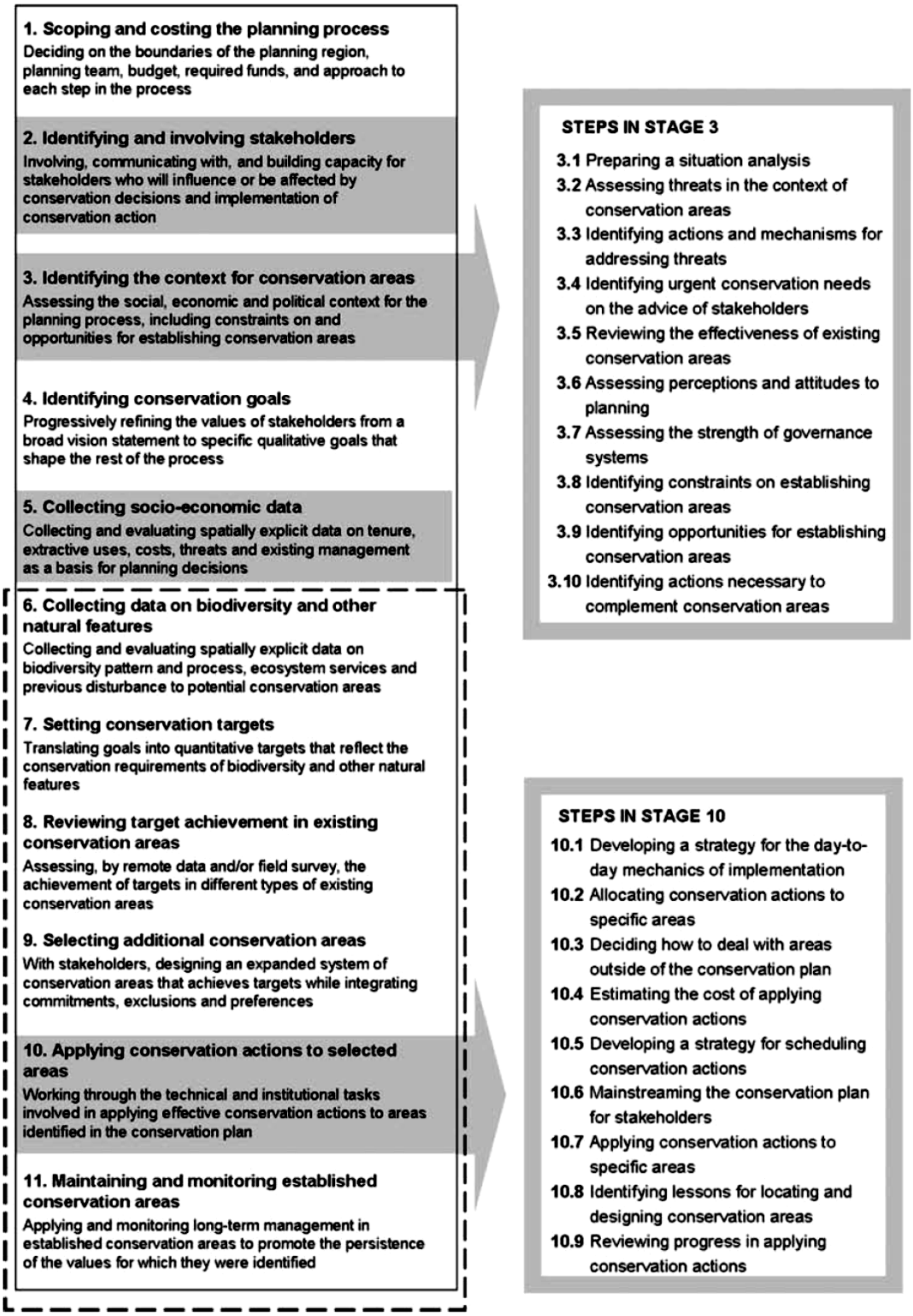
Appendix 1: Aichi Biodiversity Targets (CBD Secretariat, 2015)

Strategic goals	Targets
Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society	1. By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably. 2. By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems. 3. By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimise or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions. 4. By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.
Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use	5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced. 6. By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits. 7. By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity. 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity. 9. By 2020, invasive alien species and pathways are identified and prioritised, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment. 10. By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimised, so as to maintain their integrity and functioning.
Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity	11. By 2020, at least 17% of terrestrial and inland water, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes. 12. By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained. 13. By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.
Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services	14. By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable. 15. By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15% of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification. 16. By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation is in force and operational, consistent with national legislation.

Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building	17. By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan. 18. By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels. 19. By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied. 20. By 2020, at the latest, the mobilisation of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilisation, should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.

Appendix 2: Eleven-stage systematic conservation planning framework (Robert L. Pressey & Bottrill, 2008)



1. Scoping and costing the planning process
Deciding on the boundaries of the planning region, planning team, budget, required funds, and approach to each step in the process

2. Identifying and involving stakeholders
Involving, communicating with, and building capacity for stakeholders who will influence or be affected by conservation decisions and implementation of conservation action

3. Identifying the context for conservation areas
Assessing the social, economic and political context for the planning process, including constraints on and opportunities for establishing conservation areas

4. Identifying conservation goals
Progressively refining the values of stakeholders from a broad vision statement to specific qualitative goals that shape the rest of the process

5. Collecting socio-economic data
Collecting and evaluating spatially explicit data on tenure, extractive uses, costs, threats and existing management as a basis for planning decisions

6. Collecting data on biodiversity and other natural features
Collecting and evaluating spatially explicit data on biodiversity pattern and process, ecosystem services and previous disturbance to potential conservation areas

7. Setting conservation targets
Translating goals into quantitative targets that reflect the conservation requirements of biodiversity and other natural features

8. Reviewing target achievement in existing conservation areas
Assessing, by remote data and/or field survey, the achievement of targets in different types of existing conservation areas

9. Selecting additional conservation areas
With stakeholders, designing an expanded system of conservation areas that achieves targets while integrating commitments, exclusions and preferences

10. Applying conservation actions to selected areas
Working through the technical and institutional tasks involved in applying effective conservation actions to areas identified in the conservation plan

11. Maintaining and monitoring established conservation areas
Applying and monitoring long-term management in established conservation areas to promote the persistence of the values for which they were identified

STEPS IN STAGE 3

3.1 Preparing a situation analysis
3.2 Assessing threats in the context of conservation areas
3.3 Identifying actions and mechanisms for addressing threats
3.4 Identifying urgent conservation needs on the advice of stakeholders
3.5 Reviewing the effectiveness of existing conservation areas
3.6 Assessing perceptions and attitudes to planning
3.7 Assessing the strength of governance systems
3.8 Identifying constraints on establishing conservation areas
3.9 Identifying opportunities for establishing conservation areas
3.10 Identifying actions necessary to complement conservation areas

STEPS IN STAGE 10

10.1 Developing a strategy for the day-to-day mechanics of implementation
10.2 Allocating conservation actions to specific areas
10.3 Deciding how to deal with areas outside of the conservation plan
10.4 Estimating the cost of applying conservation actions
10.5 Developing a strategy for scheduling conservation actions
10.6 Mainstreaming the conservation plan for stakeholders
10.7 Applying conservation actions to specific areas
10.8 Identifying lessons for locating and designing conservation areas
10.9 Reviewing progress in applying conservation actions

Appendix 3: List of species with habitat suitability maps and their national Red List classification and legal status

Species	National Red List	Legal protection
Acer pseudoplatanus	LC	
Achillea atrata	LC	
Achillea millefolium	LC	
Acinos alpinus	LC	
Adenostyles alliariae	LC	
Adenostyles glabra	LC	
Agrostis alpina	LC	
Agrostis capillaris	LC	
Agrostis rupestris	LC	
Agrostis schraderiana	LC	
Agrostis stolonifera	LC	
Ajuga reptans	LC	
Alchemilla conjuncta	NE	
Alchemilla coriacea	NE	
Alchemilla glabra	NE	
Alchemilla vulgaris	NE	
Allium schoenoprasum	LC	
Androsace chamaejasme	LC	Yes
Anemone narcissiflora	LC	
Anemone nemorosa	LC	
Anthoxanthum odoratum	LC	
Anthriscus sylvestris	LC	
Anthyllis vulneraria	LC	
Aposeris foetida	LC	
Arabis alpina	LC	
Arabis caerulea	LC	
Arnica montana	LC	YES
Arrhenatherum elatius	LC	
Asplenium viride	LC	
Aster bellidiastrum	LC	
Astrantia major	LC	
Athamanta cretensis	LC	
Avenella flexuosa	LC	
Bartsia alpina	LC	
Bellis perennis	LC	
Botrychium lunaria	LC	
Brachypodium pinnatum	LC	
Briza media	LC	
Bromus erectus	LC	

Species	National Red List	Legal protection
Bromus hordeaceus	LC	
Calamagrostis varia	LC	
Caltha palustris	LC	
Campanula barbata	LC	
Campanula cochleariifolia	LC	
Campanula rhomboidalis	LC	
Campanula rotundifolia	LC	
Campanula scheuchzeri	LC	
Cardamine pratensis	LC	
Carduus defloratus	LC	
Carex atrata	LC	
Carex caryophyllea	LC	
Carex ferruginea	LC	
Carex flacca	LC	
Carex flava	LC	
Carex montana	LC	
Carex nigra	LC	
Carex ornithopoda	LC	
Carex pallescens	LC	
Carex panicea	LC	
Carex sempervirens	LC	
Carex sylvatica	LC	
Carlina acaulis	NE	YES
Carum carvi	LC	
Centaurea jacea	LC	
Centaurea montana	LC	
Centaurea scabiosa	LC	
Cerastium arvense	LC	
Cerastium fontanum	LC	
Cerastium latifolium	LC	
Chaerophyllum aureum	LC	
Chaerophyllum hirsutum	LC	
Cirsium acaule	LC	
Cirsium eriophorum	LC	
Cirsium oleraceum	LC	
Cirsium palustre	LC	
Cirsium spinosissimum	LC	
Clinopodium vulgare	LC	
Coeloglossum viride	LC	YES

Species	National Red List	Legal protection
Colchicum autumnale	LC	
Crepis aurea	LC	
Crepis biennis	LC	
Crepis pyrenaica	LC	
Crocus albiflorus	LC	YES
Cruciata laevipes	LC	
Cynosurus cristatus	LC	
Dactylis glomerata	LC	
Dactylorhiza fuchsii	LC	YES
Daucus carota	LC	
Deschampsia cespitosa	LC	
Doronicum grandiflorum	LC	
Dryas octopetala	LC	
Elyna myosuroides	LC	
Equisetum palustre	LC	
Erigeron uniflorus	LC	
Euphorbia cyparissias	LC	
Euphrasia hirtella	LC	
Euphrasia minima	LC	
Euphrasia salisburgensis	LC	
Festuca ovina	LC	
Festuca pratensis	LC	
Festuca quadriflora	LC	
Festuca rubra	LC	
Festuca violacea	LC	
Filipendula ulmaria	LC	
Fragaria vesca	LC	
Fraxinus excelsior	LC	
Galium album	LC	
Galium anisophyllon	LC	
Galium megalospermum	LC	
Galium mollugo	LC	
Galium pumilum	LC	
Gentiana acaulis	LC	
Gentiana bavarica	LC	
Gentiana campestris	LC	
Gentiana clusii	LC	
Gentiana lutea	LC	
Gentiana nivalis	LC	
Gentiana purpurea	LC	

Species	National Red List	Legal protection
Gentiana verna	LC	
Geranium sylvaticum	LC	
Geum montanum	LC	
Geum rivale	LC	
Geum urbanum	LC	
Glechoma hederacea	LC	
Globularia cordifolia	LC	
Globularia nudicaulis	LC	
Gnaphalium sylvaticum	LC	
Gymnadenia conopsea	LC	YES
Gypsophila repens	LC	
Hedysarum hedysaroides	LC	
Helianthemum nummularium	LC	
Helictotrichon pubescens	LC	
Helictotrichon versicolor	LC	
Heracleum sphondylium	LC	
Hieracium bifidum	LC	
Hieracium lactucella	LC	
Hieracium murorum	LC	
Hieracium pilosella	LC	
Hieracium villosum	LC	
Hippocrepis comosa	LC	
Holcus lanatus	LC	
Homogyne alpina	LC	
Hypericum maculatum	LC	
Hypericum perforatum	LC	
Hypochaeris radicata	LC	
Juncus articulatus	LC	
Juncus effusus	LC	
Knautia arvensis	LC	
Knautia dipsacifolia	LC	
Laserpitium latifolium	LC	
Laserpitium siler	LC	
Lathyrus pratensis	LC	
Leontodon autumnalis	LC	
Leontodon helveticus	LC	
Leontodon hispidus	LC	

Species	National Red List	Legal protection
Leucanthemum vulgare	LC	
Ligusticum mutellina	LC	
Ligusticum mutellinoides	LC	
Linaria alpina	LC	YES
Linum catharticum	LC	
Lolium perenne	LC	
Lotus corniculatus	LC	
Luzula alpinopilosa	LC	
Luzula campestris	LC	
Luzula multiflora	LC	
Luzula sylvatica	LC	
Medicago lupulina	LC	
Myosotis alpestris	LC	
Myosotis arvensis	LC	
Nardus stricta	LC	
Nigritella rhellicani	LC	YES
Onobrychis montana	LC	
Onobrychis viciifolia	LC	
Parnassia palustris	LC	
Pedicularis foliosa	LC	
Pedicularis verticillata	LC	
Phleum hirsutum	LC	
Phleum pratense	LC	
Phleum rhaeticum	LC	
Phyteuma betonicifolium	LC	
Phyteuma orbiculare	LC	
Phyteuma spicatum	LC	
Picea abies	LC	
Pimpinella major	LC	
Pimpinella saxifraga	LC	
Plantago alpina	LC	
Plantago lanceolata	LC	
Plantago major	LC	
Plantago media	LC	
Poa alpina	LC	
Poa cenisia	LC	
Poa minor	LC	
Poa pratensis	LC	
Poa supina	LC	
Poa trivialis	LC	

Species	National Red List	Legal protection
Polygala alpestris	LC	
Polygala chamaebuxus	LC	
Polygala vulgaris	LC	
Polygonum bistorta	LC	
Potentilla aurea	LC	
Potentilla crantzii	LC	
Potentilla erecta	LC	
Potentilla sterilis	LC	
Primula auricula	LC	
Primula elatior	LC	
Primula farinosa	LC	YES
Primula veris	LC	
Pritzelago alpina	LC	
Prunella vulgaris	LC	
Pulsatilla alpina	LC	
Ranunculus aconitifolius	LC	
Ranunculus acris	LC	
Ranunculus alpestris	LC	
Ranunculus bulbosus	LC	
Ranunculus montanus	LC	
Ranunculus nemorosus	LC	
Ranunculus repens	LC	
Rhinanthus alectorolophus	LC	
Rhinanthus minor	LC	
Rhododendron ferrugineum	LC	YES
Rumex acetosa	LC	
Rumex alpestris	LC	
Rumex alpinus	LC	
Rumex crispus	LC	
Sagina saginoides	LC	
Salix herbacea	LC	
Salix reticulata	LC	
Salix retusa	LC	
Salvia pratensis	LC	
Sanguisorba minor	LC	
Saxifraga aizoides	LC	
Saxifraga moschata	LC	
Saxifraga oppositifolia	LC	YES
Saxifraga paniculata	LC	YES

Species	National Red List	Legal protection
Scabiosa columbaria	LC	
Scabiosa lucida	LC	
Sedum atratum	LC	
Selaginella selaginoides	LC	
Senecio doronicum	LC	
Sesleria caerulea	LC	
Silene acaulis	LC	
Silene vulgaris	LC	
Solidago virgaurea	LC	
Stachys officinalis	LC	
Stellaria graminea	LC	
Taraxacum alpinum	LC	
Taraxacum officinale	LC	
Thesium alpinum	LC	
Thesium pyrenaicum	LC	
Thymus praecox	LC	
Thymus pulegioides	LC	
Tofieldia calyculata	LC	YES
Tragopogon pratensis	LC	
Trifolium badium	LC	
Trifolium montanum	LC	
Trifolium pratense	LC	
Trifolium repens	LC	

Species	National Red List	Legal protection
Trifolium thalii	LC	
Trisetum distichophyllum	LC	
Trisetum flavescens	LC	
Trollius europaeus	LC	YES
Tussilago farfara	LC	
Vaccinium gaultherioides	LC	
Vaccinium myrtillus	LC	
Valeriana montana	LC	
Valeriana tripteris	LC	
Veronica alpina	LC	
Veronica aphylla	LC	
Veronica arvensis	LC	
Veronica chamaedrys	LC	
Veronica officinalis	LC	
Veronica serpyllifolia	LC	
Vicia cracca	LC	
Vicia sativa	LC	
Vicia sepium	LC	
Viola biflora	LC	
Viola calcarata	LC	
Viola canina	NT	YES
Viola hirta	LC	

Appendix 4: List of species of special interest (SSI) with presence-absence data and their national Red List classification and legal status

Species	National Red List	Legal Protection
Aceras anthropophorum	VU	YES
Agrimonia procera	VU	YES
Allium carinatum	LC	YES
Allium lusitanicum	LC	YES
Allium victorialis	LC	YES
Androsace alpina	LC	YES
Androsace helvetica	LC	YES
Androsace puberula	LC	YES
Androsace pubescens	NT	YES
Androsace vandellii	LC	YES
Anemone sylvestris	CR	YES
Anthericum liliago	LC	YES
Aquilegia alpina	NT	YES
Arabis collina	VU	YES
Arctostaphylos uva-ursi	LC	YES
Artemisia genipi	LC	YES
Artemisia umbelliformis	LC	YES
Asplenium adiantum-nigrum	LC	YES
Asplenium fontanum	NT	YES
Aster alpinus	LC	YES
Aster amellus	LC	YES
Astragalus aristatus	NT	YES
Bromus racemosus	EN	YES
Bromus squarrosus	LC	YES
Buglossoides purpurocaerulea	NT	YES
Campanula latifolia	NT	YES
Carduus acanthoides	CR	YES
Carex halleriana	LC	YES
Carex lasiocarpa	NT	YES
Carex umbrosa	LC	YES
Cephalanthera damasonium	LC	YES
Cephalanthera longifolia	LC	YES
Cephalanthera rubra	LC	YES
Cephalaria alpina	VU	YES
Chamorchis alpina	LC	YES
Chenopodium vulvaria	EN	YES
Cicerbita macrophylla	VU	YES
Corallorhiza trifida	LC	YES

Species	National Red List	Legal Protection
Crepis foetida	VU	YES
Cuscuta epilinum	RE	YES
Cyclamen hederifolium	EN	YES
Cypripedium calceolus	VU	YES
Dactylorhiza maculata	CR	YES
Dactylorhiza majalis	LC	YES
Dactylorhiza sambucina	NT	YES
Danthonia decumbens	LC	YES
Delphinium elatum	NT	YES
Diphasiastrum alpinum	LC	YES
Diphasiastrum tristachyum	RE	YES
Dracocephalum ruyschiana	NT	YES
Eleocharis uniglumis	NT	YES
Epilobium anagallidifolium	LC	YES
Epipactis atrorubens	LC	YES
Epipactis helleborine	LC	YES
Epipactis microphylla	NT	YES
Epipactis purpurata	LC	YES
Epipogium aphyllum	NT	YES
Equisetum variegatum	LC	YES
Eriophorum vaginatum	LC	YES
Eryngium alpinum	VU	YES
Fourraea alpina	NT	YES
Galeopsis bifida	VU	YES
Galeopsis ladanum	NT	YES
Gentiana ciliata	LC	YES
Gentiana cruciata	VU	YES
Geranium phaeum	NT	YES
Goodyera repens	LC	YES
Gymnadenia odoratissima	LC	YES
Helictotrichon pratense	LC	YES
Huperzia selago	LC	YES
Hypochaeris uniflora	LC	YES
Iris pseudacorus	LC	YES
Juncus arcticus	VU	YES
Juniperus sabina	LC	YES

Species	National Red List	Legal Protection
Leontodon pseudocrispus	LC	YES
Leontopodium alpinum	LC	YES
Leucojum vernum	LC	YES
Lilium martagon	LC	YES
Limodorum abortivum	NT	YES
Listera cordata	LC	YES
Listera ovata	LC	YES
Luzula forsteri	NT	YES
Lycopodium annotinum	LC	YES
Lycopodium clavatum	NT	YES
Mespilus germanica	NT	YES
Moneses uniflora	LC	YES
Monotropa hypopitys	LC	YES
Myosotis cespitosa	VU	YES
Neottia nidus avis	LC	YES
Ophrys apifera	VU	YES
Ophrys holosericea	VU	YES
Ophrys insectifera	NT	YES
Orchis mascula	LC	YES
Oreopteris limbosperma	LC	YES
Orobanche elatior	EN	YES
Orobanche laserpitii sileris	NT	YES
Orobanche teucrii	LC	YES
Paradisea liliastrum	LC	YES
Phyllitis scolopendrium	LC	YES
Pinguicula alpina	LC	YES
Pinguicula vulgaris	LC	YES
Platanthera bifolia	LC	YES
Polypodium interjectum	NT	YES
Polystichum setiferum	LC	YES
Potentilla palustris	LC	YES
Potentilla thuringiaca	VU	YES
Pseudorchis albida	LC	YES
Pulsatilla apiifolia	LC	YES
Pyrola chlorantha	VU	YES
Pyrola minor	LC	YES
Pyrola rotundifolia	LC	YES
Pyrus pyraster	LC	YES
Ranunculus thora	NT	YES

Species	National Red List	Legal Protection
Rhinanthus serotinus	VU	YES
Rosa caesia	LC	YES
Rosa glauca	LC	YES
Rosa majalis	VU	YES
Rosa micrantha	NT	YES
Rosa spinosissima	LC	YES
Ruscus aculeatus	LC	YES
Salix daphnoides	LC	YES
Salix pentandra	NT	YES
Salix repens	NT	YES
Saussurea depressa	VU	YES
Saxifraga granulata	EN	YES
Senecio sylvaticus	VU	YES
Serratula macrocephala	NT	YES
Serratula tinctoria	NT	YES
Silaum silaus	NT	YES
Streptopus amplexifolius	LC	YES
Traunsteinera globosa	LC	YES
Trifolium alpestre	LC	YES
Trifolium ochroleucon	VU	YES
Trifolium spadiceum	VU	YES
Trinia glauca	VU	YES
Valeriana pratensis	EN	YES
Valeriana wallrothii	VU	YES
Veronica acinifolia	CR	YES
Viola mirabilis	NT	YES
Woodsia pulchella	EN	YES

Appendix 5: Proportion of distribution remaining for SSI features in relation to proportion of landscape removed

(1) CAZ with biodiversity features and ethical weighting where weight=1 for all species (scenario AA1)

(2) ABF with biodiversity features and ethical weighting where weight=1 for all species (scenario AA2)

(3) CAZ with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB1)

(4) ABF with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB2)

(5) CAZ with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC1)

(6) ABF with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC2)

(7) CAZ with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD1)

(8) ABF with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD2)

(9) CAZ with the 4th weighting strategy and a mask to exclude urban areas (scenario BA1)

(10) ABF with the 4th weighting strategy and a mask to exclude urban areas (scenario BA2)

(11) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB1)

(12) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB2)

(13) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC1)

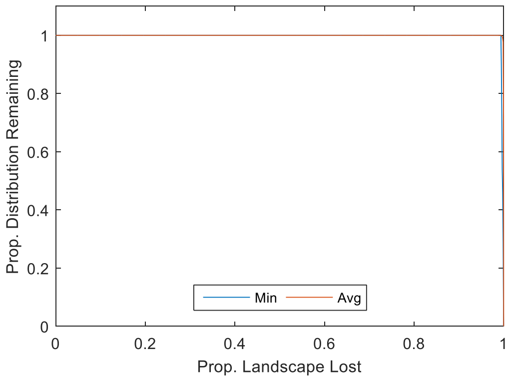
(14) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC2)

(15) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD1)

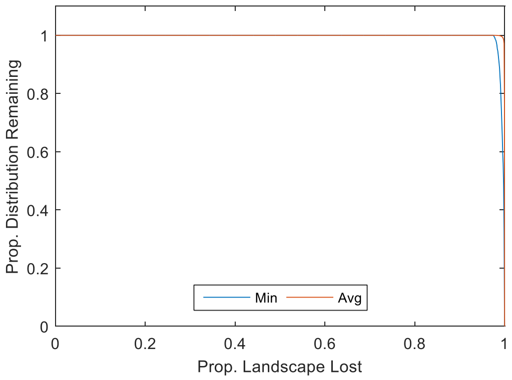
(16) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD2)

(17) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C1)

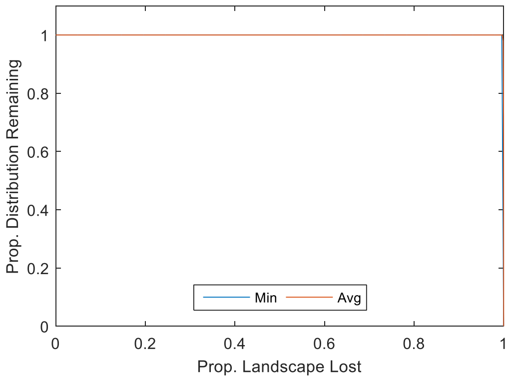
(18) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C2)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

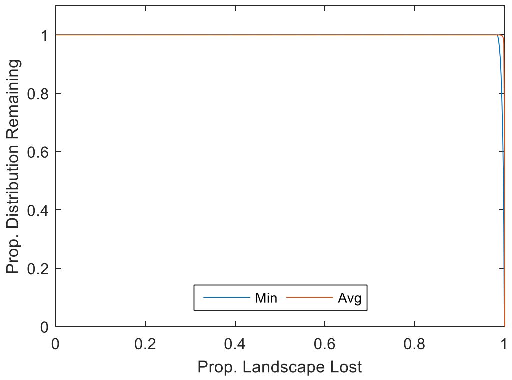
(1)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

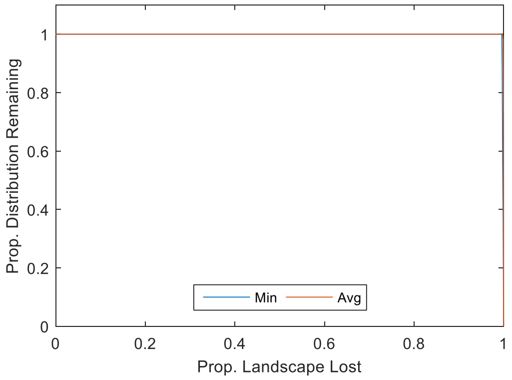
(2)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

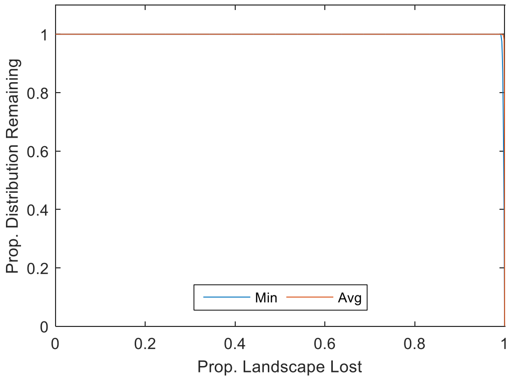
(3)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

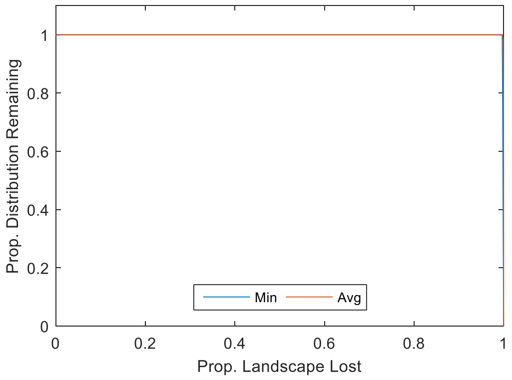
(4)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

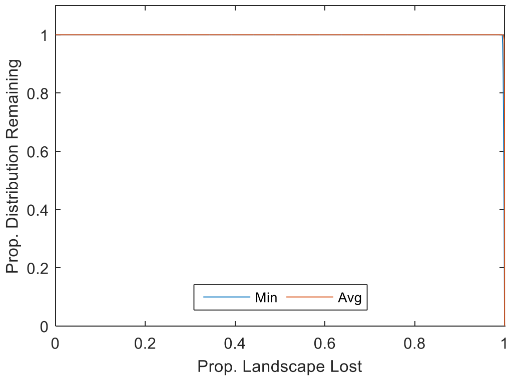
(5)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

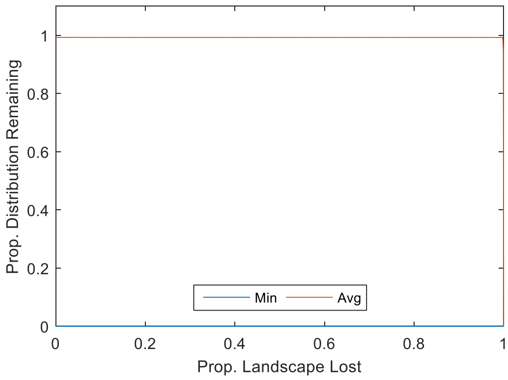
(6)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

(7)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

(8)



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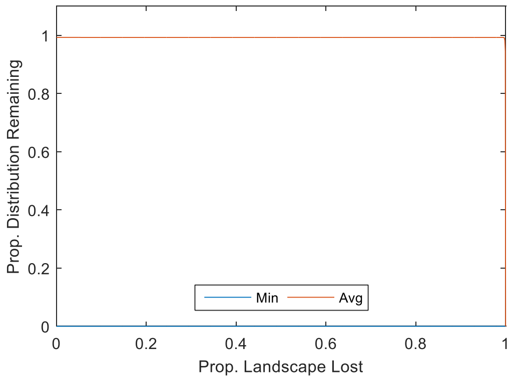

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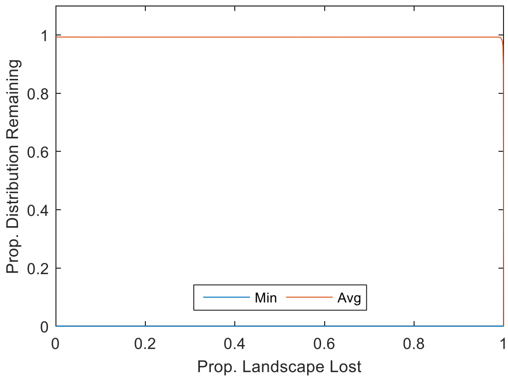

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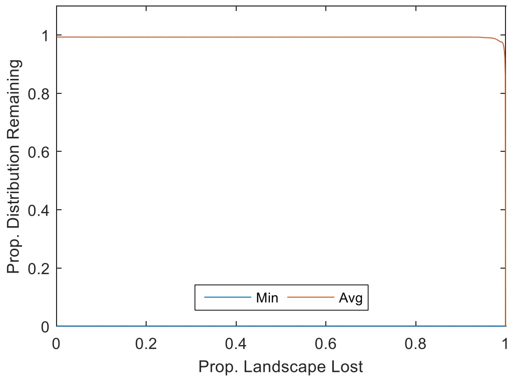

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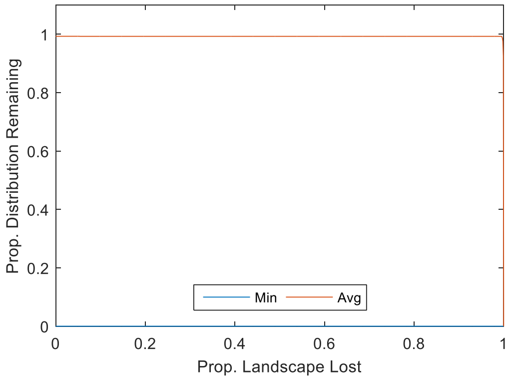

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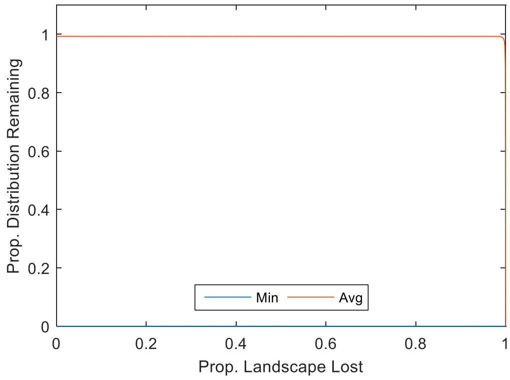

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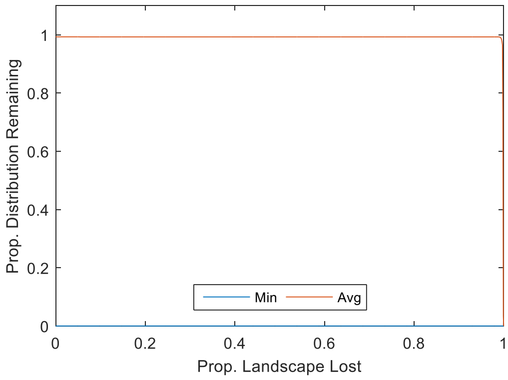

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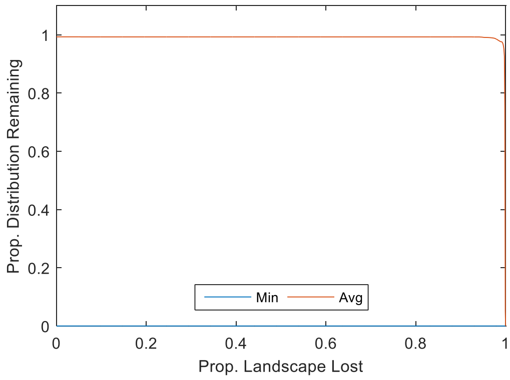

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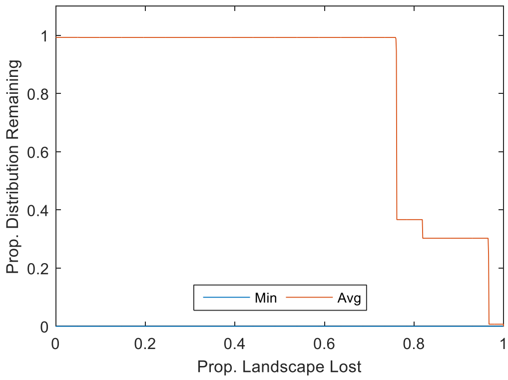
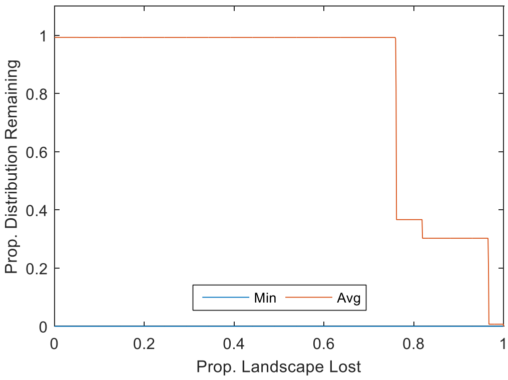

Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost

(17)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost

(18)

Appendix 6: Weighted extinction risk in relation to proportion of landscape removed

(1) CAZ with biodiversity features and ethical weighting where weight=1 for all species (scenario AA1)

(2) ABF with biodiversity features and ethical weighting where weight=1 for all species (scenario AA2)

(3) CAZ with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB1)

(4) ABF with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB2)

(5) CAZ with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC1)

(6) ABF with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC2)

(7) CAZ with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD1)

(8) ABF with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD2)

(9) CAZ with the 4th weighting strategy and a mask to exclude urban areas (scenario BA1)

(10) ABF with the 4th weighting strategy and a mask to exclude urban areas (scenario BA2)

(11) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB1)

(12) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB2)

(13) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC1)

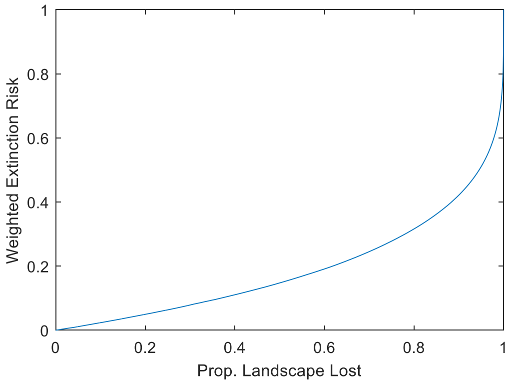
(14) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC2)

(15) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD1)

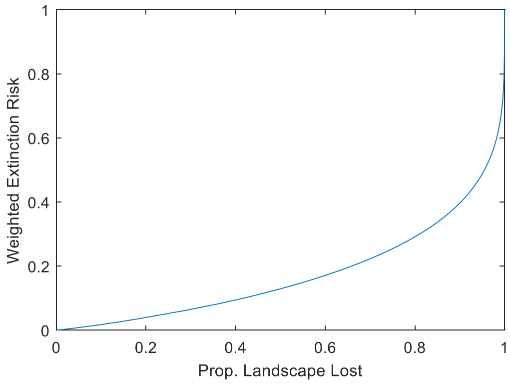
(16) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD2)

(17) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C1)

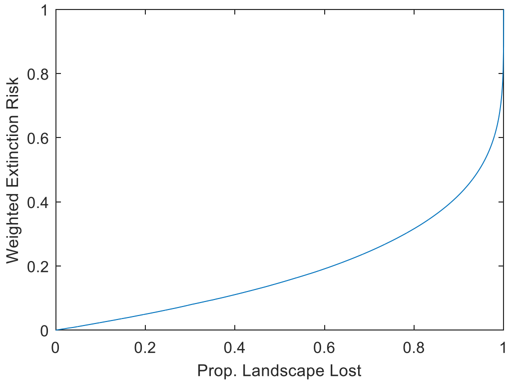
(18) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C2)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

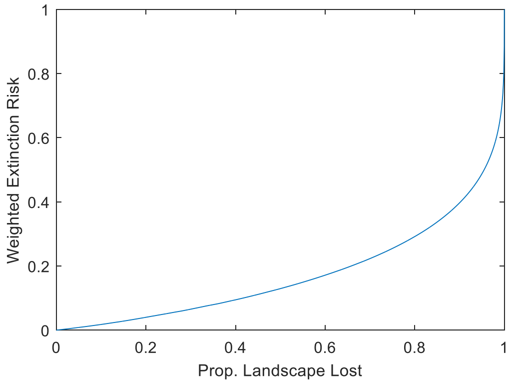
(1)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

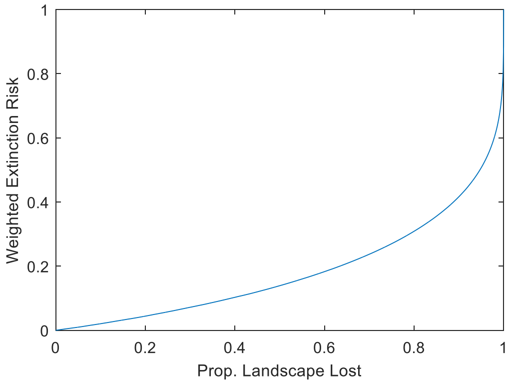
(2)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

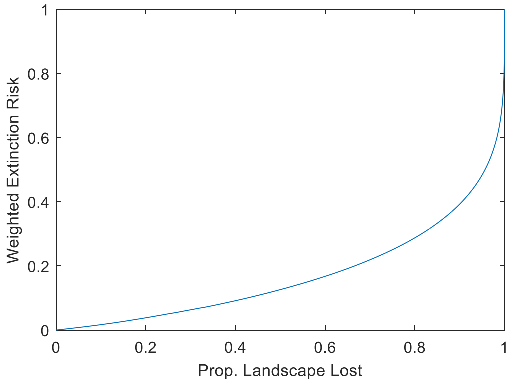
(3)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

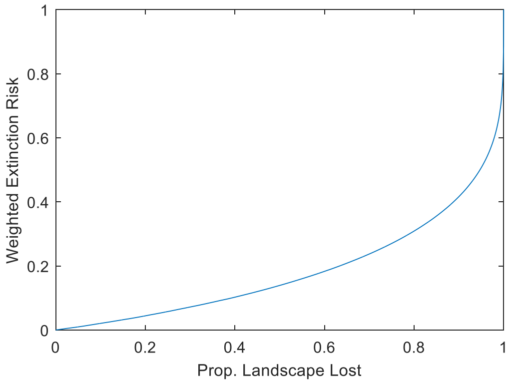
(4)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

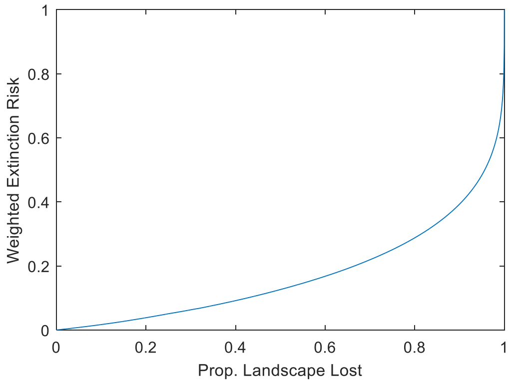
(5)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

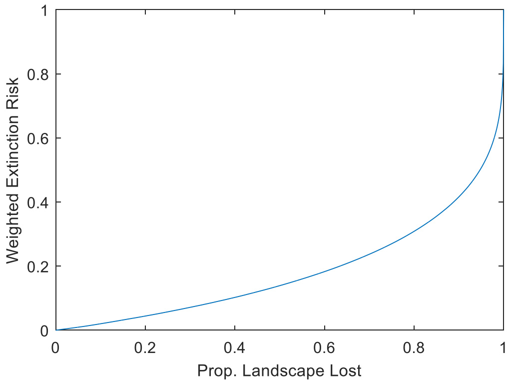
(6)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

(7)


Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
0
0.2
0.4
0.6
0.8
1

(8)



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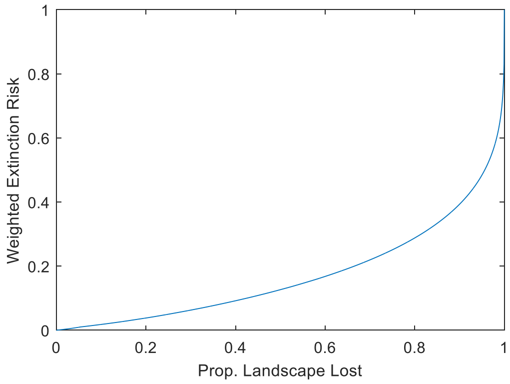

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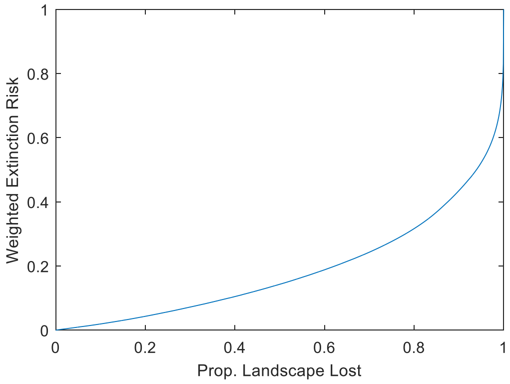

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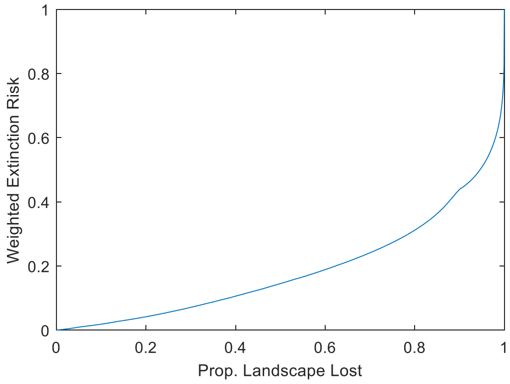

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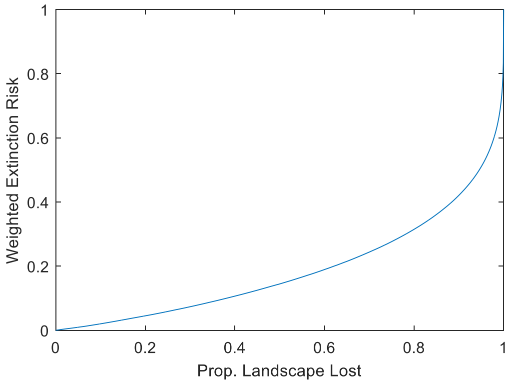

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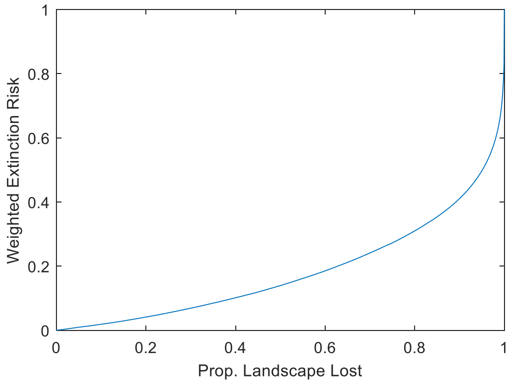

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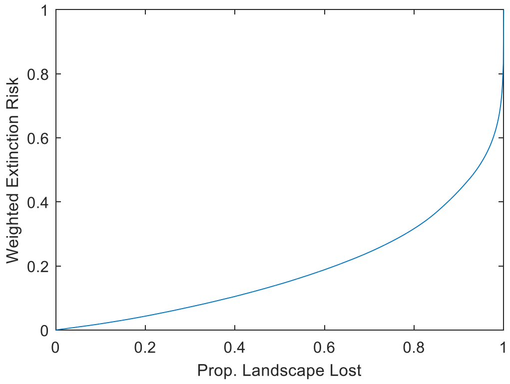

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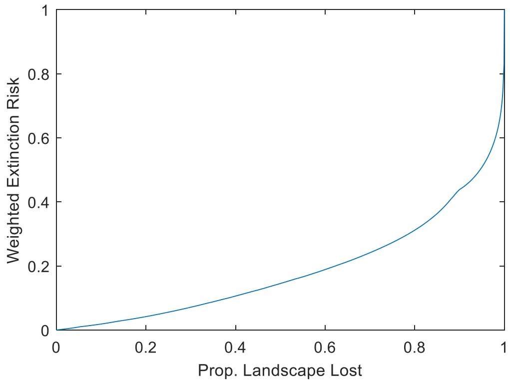
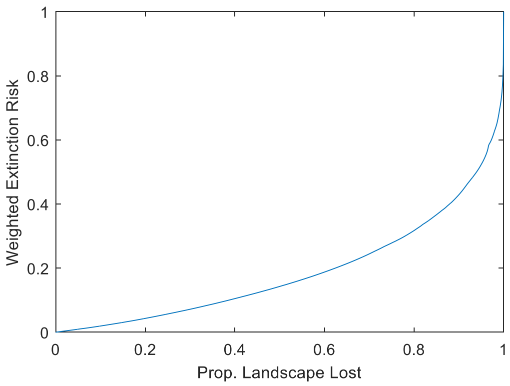
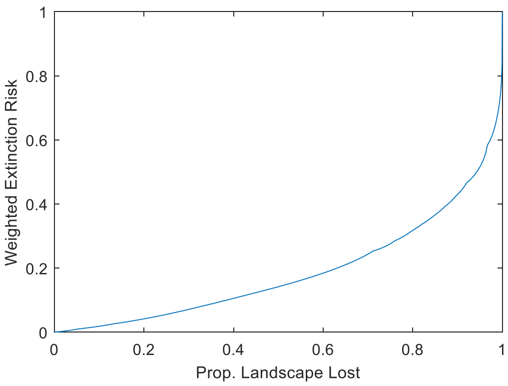


(16)


1
0.8
0.6
0.4
0.2
0
Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost

(17)


1
0.8
0.6
0.4
0.2
0
Weighted Extinction Risk
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost

(18)

Appendix 7: Proportion of distribution remaining in relation to proportion of landscape removed

(1) CAZ with biodiversity features and ethical weighting where weight=1 for all species (scenario AA1)

(2) ABF with biodiversity features and ethical weighting where weight=1 for all species (scenario AA2)

(3) CAZ with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB1)

(4) ABF with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB2)

(5) CAZ with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC1)

(6) ABF with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC2)

(7) CAZ with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD1)

(8) ABF with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD2)

(9) CAZ with the 4th weighting strategy and a mask to exclude urban areas (scenario BA1)

(10) ABF with the 4th weighting strategy and a mask to exclude urban areas (scenario BA2)

(11) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB1)

(12) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB2)

(13) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC1)

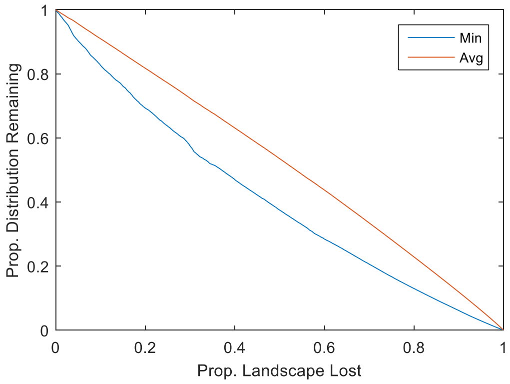
(14) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC2)

(15) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD1)

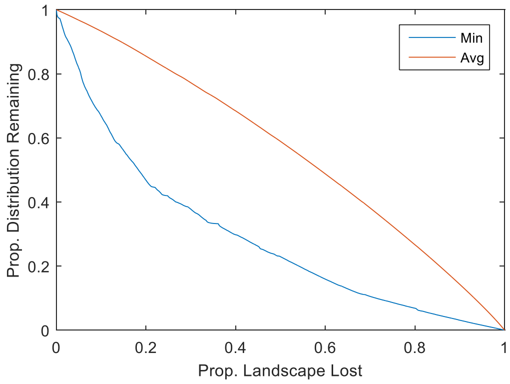
(16) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD2)

(17) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C1)

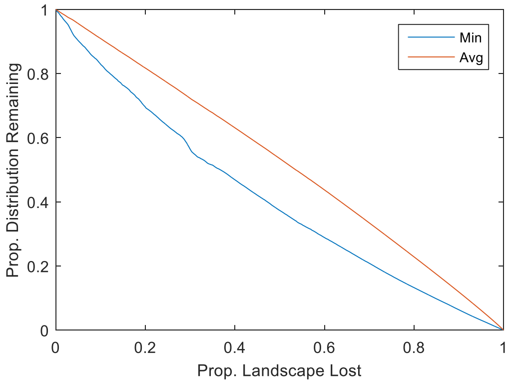
(18) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C2)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

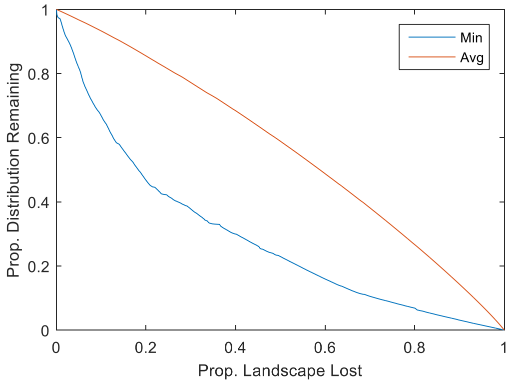
(1)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

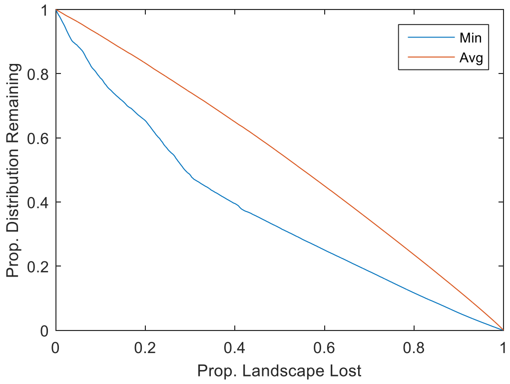
(2)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

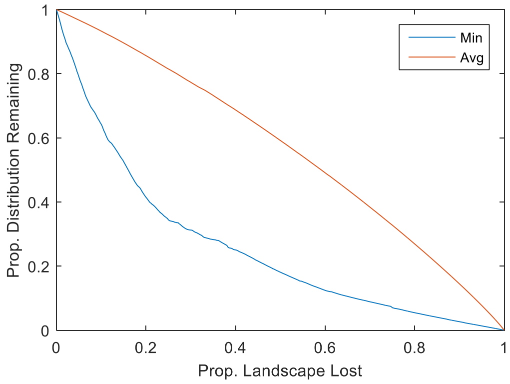
(3)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

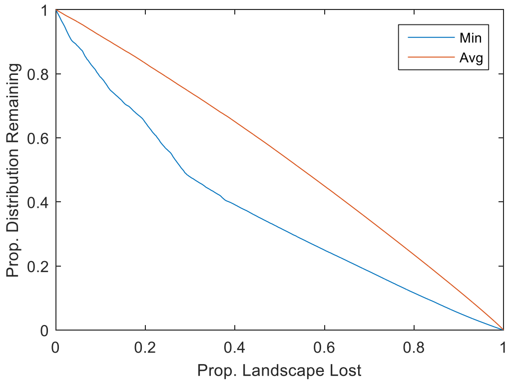
(4)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

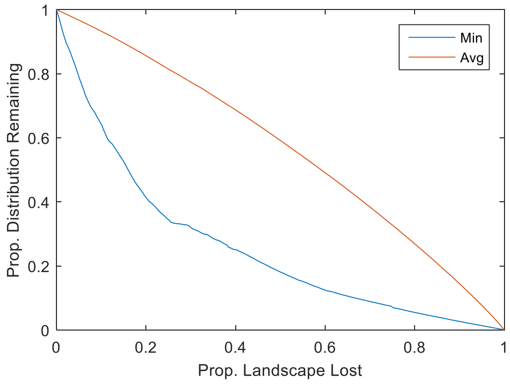
(5)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

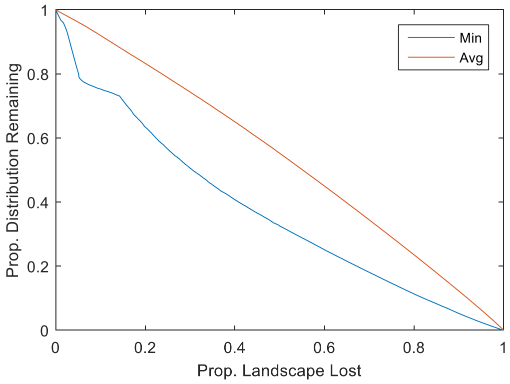
(6)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

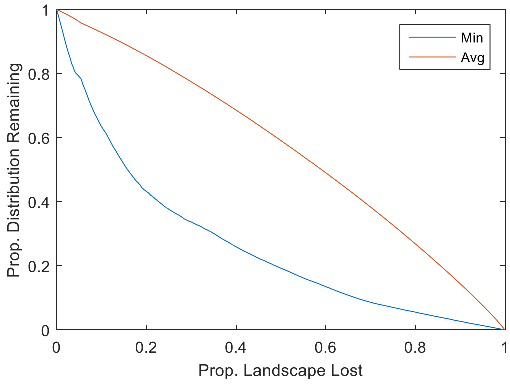
(7)


Prop. Distribution Remaining
Prop. Landscape Lost
Min
Avg
0
0.2
0.4
0.6
0.8
1

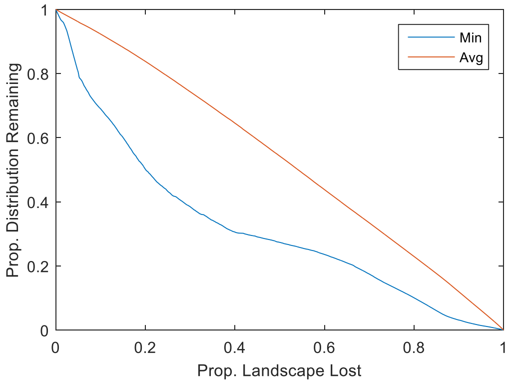
(8)



(9)



(10)



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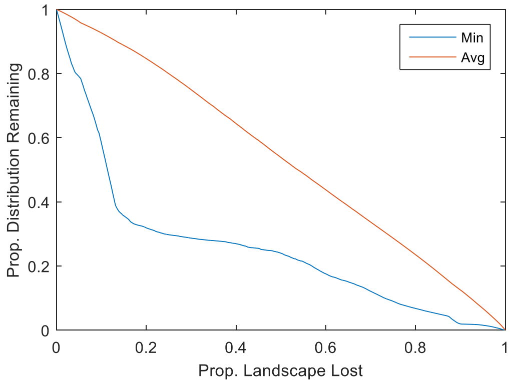
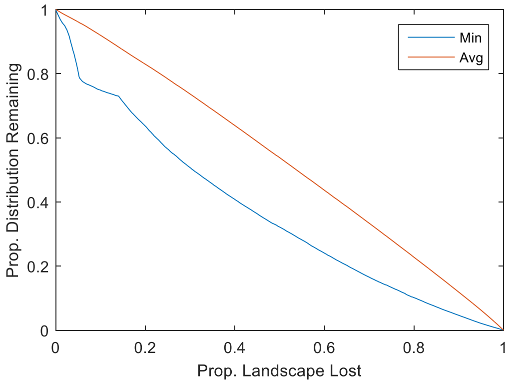
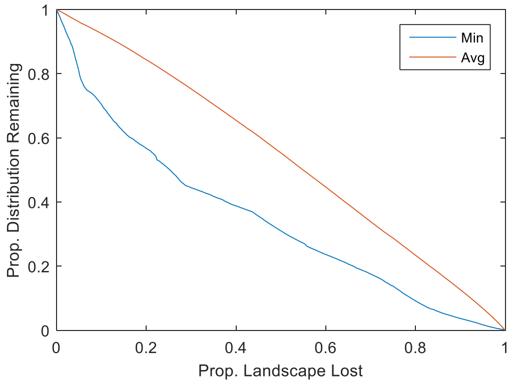


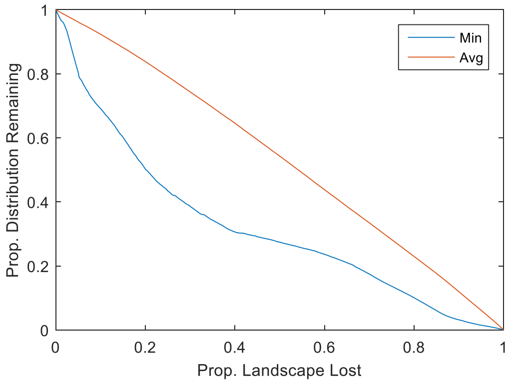
(12)



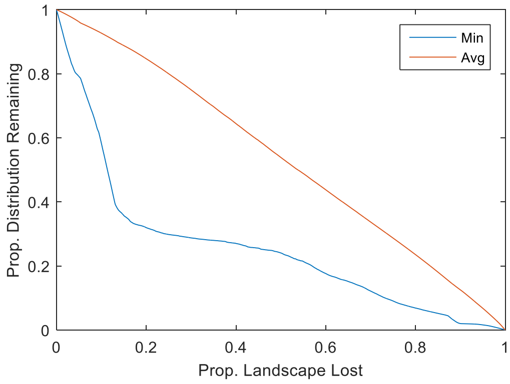
(13)



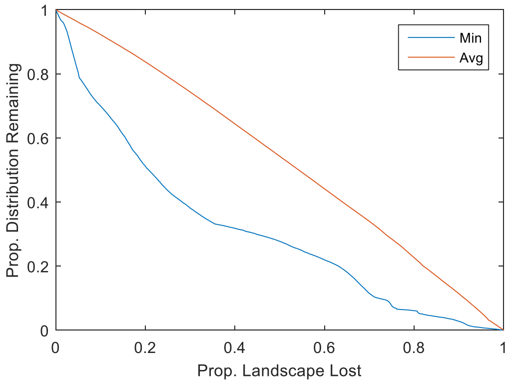
(14)



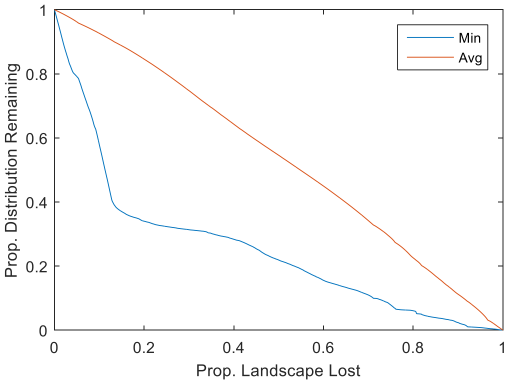
(15)



(16)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

(17)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Prop. Landscape Lost
Min
Avg

(18)

Appendix 8: Proportion of distribution remaining in relation to cost

(1) CAZ with biodiversity features and ethical weighting where weight=1 for all species (scenario AA1)

(2) ABF with biodiversity features and ethical weighting where weight=1 for all species (scenario AA2)

(3) CAZ with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB1)

(4) ABF with biodiversity features and National Red List weighting where LC/NE/DD=1, NT=2, VU=3, EN=4, CR=5 and RE=6 (scenario AB2)

(5) CAZ with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC1)

(6) ABF with biodiversity features and legal status weighting where protected=3 and not protected=1 (scenario AC2)

(7) CAZ with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD1)

(8) ABF with biodiversity features and National Red list weighting with a 2-point bonus if also legally protected (scenario AD2)

(9) CAZ with the 4th weighting strategy and a mask to exclude urban areas (scenario BA1)

(10) ABF with the 4th weighting strategy and a mask to exclude urban areas (scenario BA2)

(11) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB1)

(12) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB2)

(13) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC1)

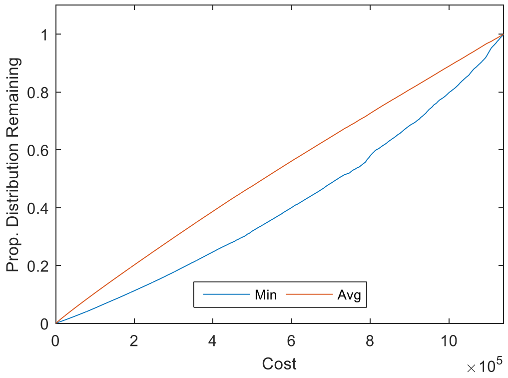
(14) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated political cost (scenario BC2)

(15) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD1)

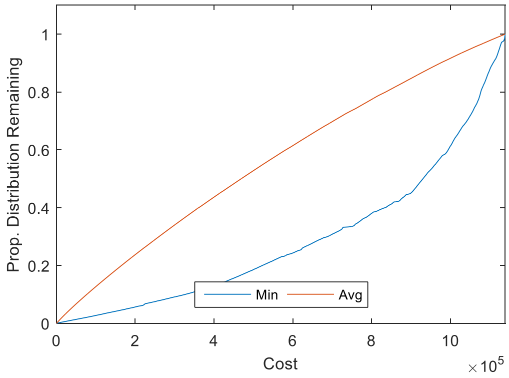
(16) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD2)

(17) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C1)

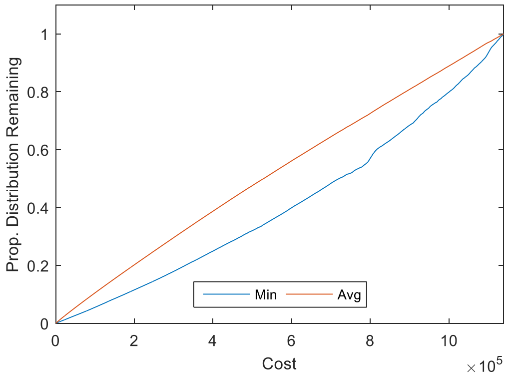
(18) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C2)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

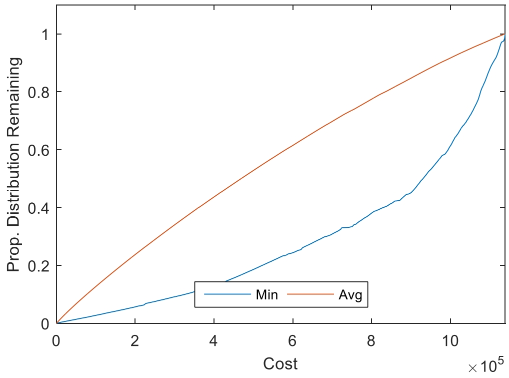
(1)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

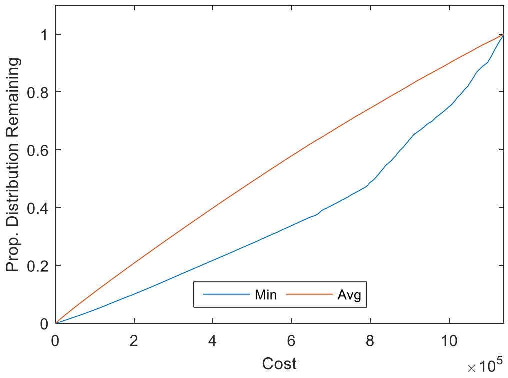
(2)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

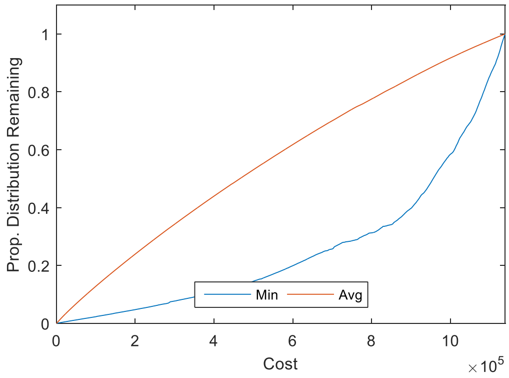
(3)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

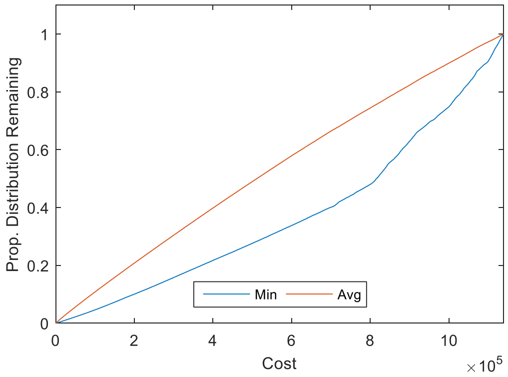
(4)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

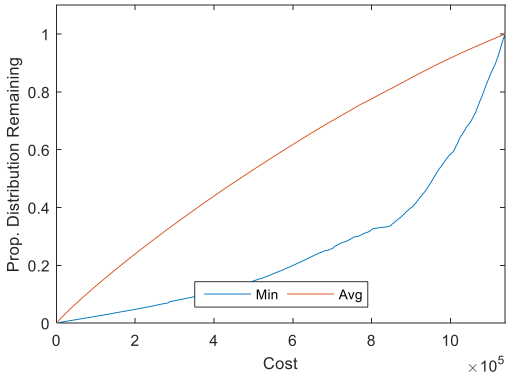
(5)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

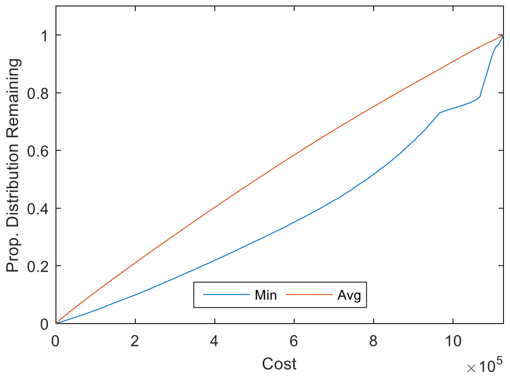
(6)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

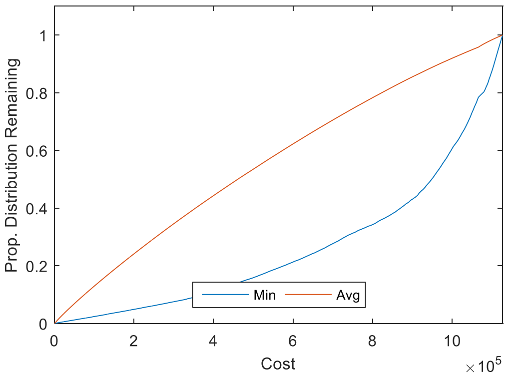
(7)


Prop. Distribution Remaining
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
Cost
×10^5
Min
Avg

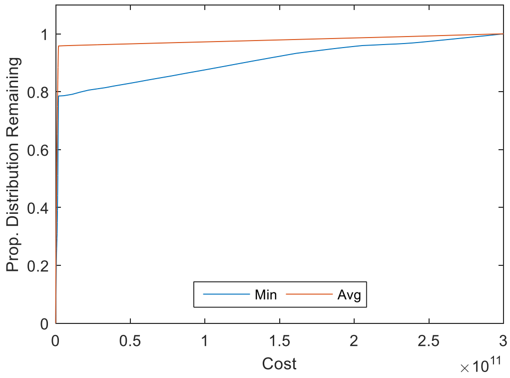
(8)



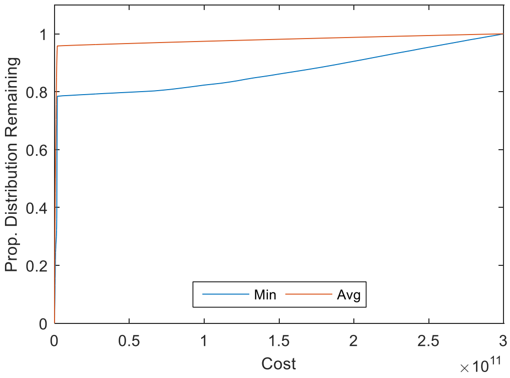
(9)



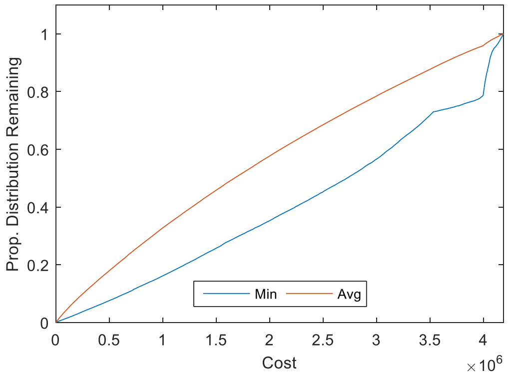
(10)



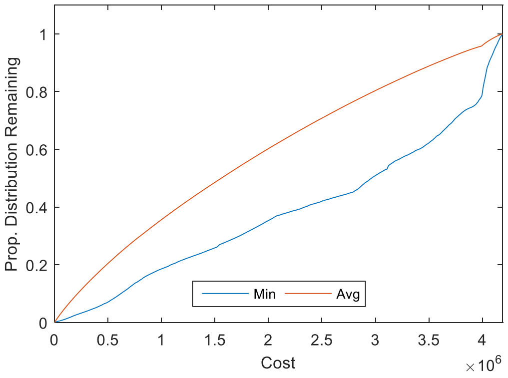
(11)



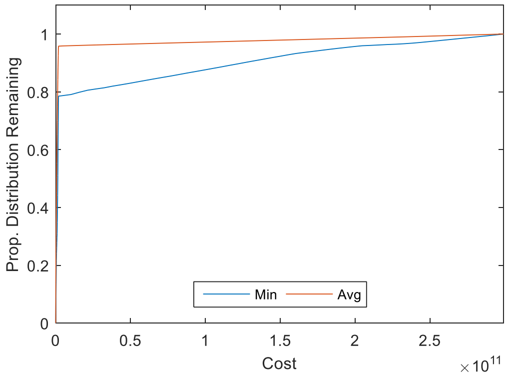
(12)



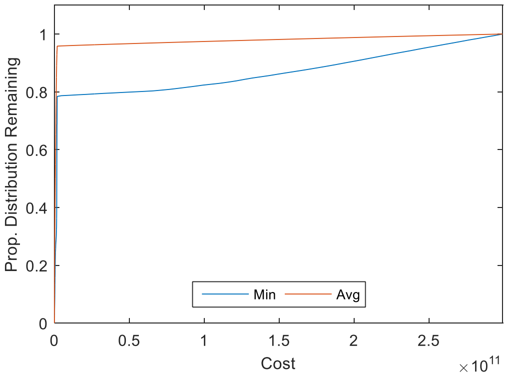
(13)



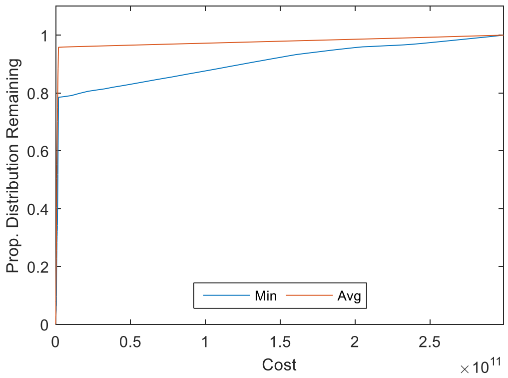
(14)



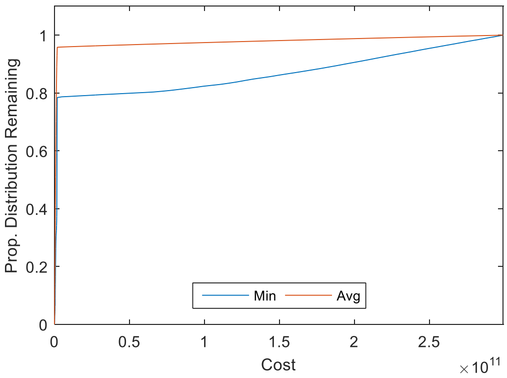
(15)



(16)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
Cost
$\times 10^{11}$
Min
Avg

(17)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
Cost
$\times 10^{11}$
Min
Avg

(18)

Appendix 9: Proportion of distribution remaining in relation to cost (detail view for scenarios including acquisition costs)

(1) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB1)

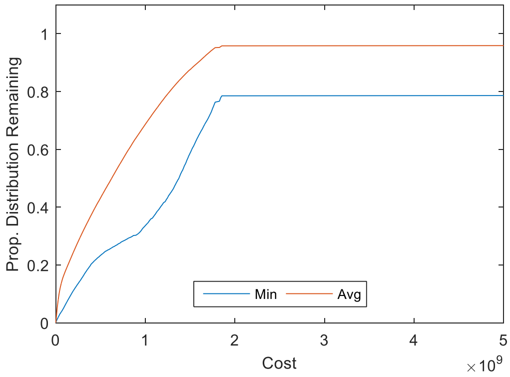
(2) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for estimated acquisition cost (scenario BB2)

(3) CAZ with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD1)

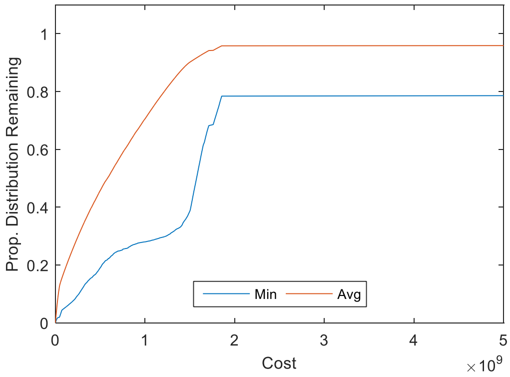
(4) ABF with the 4th weighting strategy and a mask to exclude urban areas, accounting for both acquisition and political costs (scenario BD2)

(5) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C1)

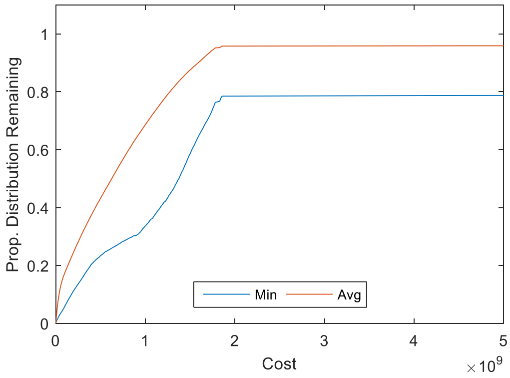
(6) CAZ with the 4th weighting strategy and a mask to exclude urban areas and block protected areas according to their weight, accounting for acquisition and political costs (scenario C2)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
1
2
3
4
5
Cost
×10^9

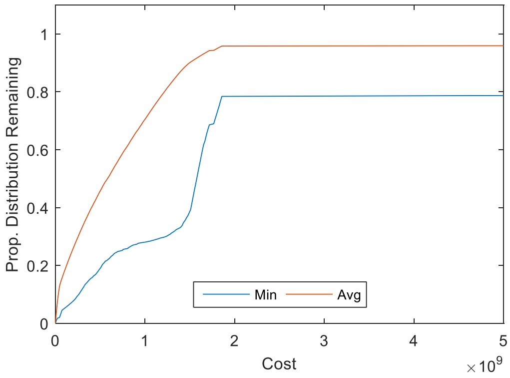
(1)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
1
2
3
4
5
Cost
×10^9

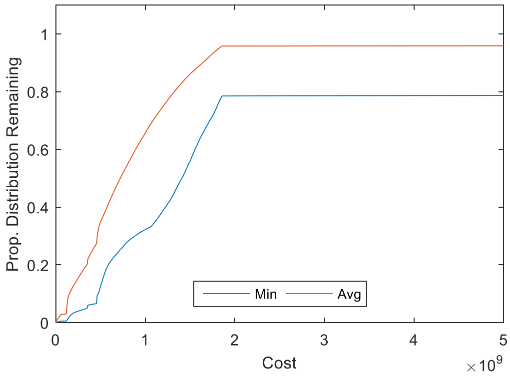
(2)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
1
2
3
4
5
Cost
×10^9

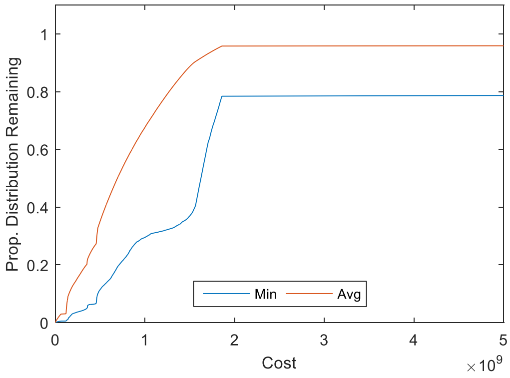
(3)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
1
2
3
4
5
Cost
×10^9

(4)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
1
2
3
4
5
Cost
×10^9

(5)


Prop. Distribution Remaining
1
0.8
0.6
0.4
0.2
0
Min
Avg
0
1
2
3
4
5
Cost
×10^9

(6)